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EVALUATION OF CANDIDATE MATERIALS FOR FINES FILTER MEDIA IN THE C2 CANISTER

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13. ABSTRACT *(Maximum 200 words)*

This report contains the test procedures and results of the physical and mechanical properties of the current fines filter medium used in the C2 canister and four similar candidate filter media for potential use in the C2 canister. The properties evaluated in this study include: air flow resistance, aerosol filtration efficiency, tensile strength, and mildew resistance. The current C2 canister fines filter medium evaluated was TROY MILLS 1-2.25-075 Troytuf, and the four candidate materials evaluated were Foss Manufacturing's OAG630, Ahlstrom Filtration's R2817, Snow Filtration's Style 342, and 3M Company's Filtrate G0104. There was 50 C2 canisters manufactured with each of the four candidate fines filter media and were tested for the following: aerosol filtration efficiency, air flow resistance, and charcoal fines emissions. This study was performed to generate a Military Specification for the fines filter media to eliminate a sole source item in the C2 canister technical data package.

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EXECUTIVE SUMMARY

The purpose of this study was to evaluate physical and mechanical properties of the current Troy Mills 1-2.25-075 Troytuf® C2 canister fines filter medium. Results from these evaluations were used to establish baseline performance standards for the C2 fines filter medium. These results will be included in a Military Specification, which will give a complete description of requirements a material will have to meet if it is to be an acceptable C2 canister fines filter. The properties evaluated in this study include: airflow resistance, aerosol filtration efficiency, tensile strength, and mildew resistance.

In addition to evaluating the current C2 fines filter medium, four alternative media were evaluated to determine if they would be useable as C2 fines filters. Performance tests were conducted on these media in an identical fashion as the Troytuf®. The four candidate materials were: Foss Manufacturing's OAG630, Ahlstrom Filtration's R2817, Snow Filtration's Style 342, and 3M Company's Filtrete® G0104.

Results from the physical properties evaluations demonstrate that the media perform similarly, but there are some differences between the alternative media and Troytuf®. None of the media supported the growth of fungus. Tensile strength was generally a function of fabric direction and ranged from 3.6 lbs force for Ahlstrom R2817 to 59 lbs force for Foss OAG630. Airflow resistance was dependent upon the state of compression for Troytuf®, Snow, and Foss media and was less than 1 mm H_2O at flow rates equivalent to 85 lpm through 10 cm diameter discs of material. Aerosol filtration efficiency was particle size and material dependent. The Troytuf® medium filtered 46 percent of 50 μm particles, Ahlstrom medium 36 percent, Snow, Foss, and 3M media had efficiencies of 85 to 95 percent.

Test C2 canisters were fabricated incorporating each of the five C2 fines filter media. Test canisters were evaluated for aerosol filtration efficiency, airflow resistance, and charcoal fines emissions. Canister performance was comparable for all test canisters except those employing the 3M Filtrete® medium. Difficulties encountered during canister fabrication resulted in poor performance for the 3M Filtrete® medium, and airflow resistance and charcoal fines emissions were higher than for C2 canisters with Troytuf®.

Our results indicate that there are media commercially available that could be used as alternatives to the current sole source Troytuf® without degrading canister performance. From this study, Foss Manufacturing's OAG630 and Snow Filtration's Style 342 are the best performing alternatives among the media examined.

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PREFACE

The work described in this report was authorized under Contract No. DLA900-86-C-2045, (Task 210) Modification P00240. This work was started in August 1990 and completed in December 1991.

The use of trade names or manufacturers' names in this report does not constitute an official endorsement of any commercial products. This report may not be cited for purposes of advertisement.

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EVALUATION OF CANDIDATE MATERIALS FOR FINES FILTER MEDIA IN THE C2 CANISTER

1. INTRODUCTION

The purpose of the fines filter medium in a respirator canister is to contain the charcoal bed and retain any charcoal fines that may be shed from the coarse granular charcoal. The fines filter medium must possess several properties to function properly. It must have sufficient tensile strength to resist tearing when the charcoal bed is compressed. It must have minimal resistance to air flow so as not to add substantially to the total breathing resistance of the canister, yet it must filter charcoal fines so the user does not inhale charcoal dust. It also must be nontoxic and nonhazardous. Other physical properties such as weight, thickness, and melting temperature need to be considered for durability and fabrication procedures.

Currently, Troy Mills' Troytuf® 1-2.25-075 is the only accepted C2 canister fines filter medium. There are no formal specifications regarding physical properties or performance standards which the medium must meet. Consequently, specifications for these properties and performance standards must be established before other filter media can be evaluated and considered for use as potential replacement materials.

2. OBJECTIVE

The first objective of this project was to perform a battery of baseline tests on the current Troytuf® medium to establish the performance criteria for the C2 canister fines filter medium. Four alternative media were selected from commercial suppliers and were tested to provide comparison data. These alternative media were then used to fabricate experimental (test) C2 canisters for additional testing to compare their performance against canisters incorporating Troytuf®.

The second objective was to use results from the above tests to supply input to draft a Military Specification. That document will establish the performance requirements and test methods to be used to qualify a material as an acceptable fines filter medium for use in C2 canisters.

3. MATERIAL PROCUREMENT

The first step of this project was to identify suitable alternative media for the baseline tests. Numerous felt, fabric, and filter media manufacturers supply a wide range of products. The search for alternative media was conducted to provide materials nearly identical to the current Troytuf® and new media which may perform better, including electrostatic material. We solicited suitable samples from manufacturers by sending them a description of the function of the medium and samples of Troytuf®. We requested that they determine if they had any appropriate materials, and, if so, to provide samples. Table 1 is a list of the suppliers we contacted, contact name, telephone number, and an indication of whether samples were received. Of the twenty companies contacted, 11 provided samples. Companies that did not send samples either did not respond or could not supply an applicable material. This list is in no way exhaustive of potential suppliers; however, it provides a representative sampling of the types of filter media commercially available.

We obtained a wide variety of media from those suppliers that responded. Generally, the media were made of polymer fibers, either polypropylene or polyester, and they exhibited different properties, depending on the fabrication process. For instance, the Troytuf® is a needle-punched, nonwoven felt fabric. Other materials are melt-blown, spun-laced, or matted, and exhibit different fiber matrices, hence, different physical properties. Two samples of electrostatic media were obtained.

The process to select four candidates for baseline testing from the many samples collected was based on a qualitative assessment of air flow resistance and our engineering judgment. Expected filtration efficiency was also considered, but to a lesser degree than air flow resistance. Other properties had little or no bearing on the selection unless they made the medium obviously unacceptable, e.g., excessive thickness. Our rejection of a material, however, does not necessarily mean that it is totally inappropriate or that it should be precluded from further examination, but only that we felt others were more worthy of evaluation at this time. The four alternative media selected for baseline tests were:

- Foss Manufacturing's OAG630
- Ahlstrom Filtration's R2817
- Snow Filtration's Style 342 (manufactured by Cardel Fabrics)
- 3M Company's Filtrete® G0104.

Table 1. Summary of Alternative Fines Filter Media Search

	Company	Contact	Phone	Sample(s)
1.	National Filter Media Corporation	Tom Larson	609-235-2641	No
2.	Great Lakes Filter Media	Al Stein/Mike Subia	313-894-1950	No
3.	Mine Safety and Appliance	Dick Miller	412-733-9100	No
4.	Felters Company	Ted Bryant	800-845-7596	Yes
5.	3M Company	Fred Sorgenfrei	612-733-7527	Yes
6.	DuPont	Grace Apple	302-892-7765	Yes
7.	American Felt and Filter Company	Bob Heintz	914-562-5311	No
8.	Farr Company		213-772-5221	No
9.	John Mansville	Lee Shearing	502-245-1220	No
10.	HEPA		714-630-5700	No
11.	Hollingsworth & Vose	Jeff Taylor	508-668-0295	Yes
12.	Snow Filtration	Frank Strittmatter	513-542-2000	Yes
13.	Ahlstrom Filtration	Bob Cornell Pete Haughton	717-486-5982 717-486-3438	Yes
14.	Freudenberg	Bill Scheeler	508-454-0461	Yes
15.	James River	Judith Ball	804-644-5411	No
16.	Fiberweb	Steve Fisher Mike Shaltry	803-240-2656 215-345-9582	No
17.	Foss Manufacturing Company	Gordon Goodwin	508-374-0121	Yes
18.	Politex	Richard Shaw William Hart	912-781-8088 708-869-0088	Yes
19.	Troy Mills	Denise Record	603-242-7711	Yes
20.	Rodel	Lou Fuhrmann	302-366-0500	No

4. TECHNICAL APPROACH

4.1 Test Matrix

The test matrix, shown in Figure 1, was divided between baseline tests of filter media and experimental canister tests. All five materials underwent a series of identical baseline tests so that a quantitative comparison of the media could be made. The five materials were batched and tested in a random order to eliminate any bias introduced by the test operator or equipment performance. Baseline tests were conducted to determine mildew resistance, tensile strength, air flow resistance, and filtering efficiency of filter media, using 20 specimens in each test. In addition, manufacturers were asked to supply data and the method used to measure melt temperature, base weight, and thickness. Next, 50 test C2 canisters of each of the five media were fabricated. These canisters were subjected to a series of tests to determine aerosol filtration efficiency, air flow resistance, and charcoal fines emissions (shaker test). Finally, eight canisters containing the Troytuf® medium were destroyed to verify canister charcoal volume.

4.2 Baseline Tests

The mildew resistance and tensile strength tests were performed by subcontractors who regularly perform these types of tests. Details of the procedures can be found in the referenced American Society for Testing and Materials (ASTM) test methods; the subcontractors' reports are presented in Appendix A. The air flow resistance and aerosol filtering efficiency tests were unique to this study; therefore, standard methods were modified to accommodate our needs. An overview of these methods is presented below. The interested reader is referred to Appendix A for detailed discussions of the test systems and procedures implemented.

Sample	ID	Baseline (Filter Medium Only)									C2 Test Canisters				
		Mildew Resistance	Tensile Strength		Filtering Efficiency				Air Flow Resistance		Filter Efficiency		Air Flow Resistance		Charcoal Fines Emission
			MD[(a)]	CMD[(b)]	1.1μm PSL[(c)]	5μm ARD[(d)]	20μm SC[(e)]	50μm SC	C[(f)]	UC[(g)]	32 lpm	85 lpm	32 lpm	85 lpm	
Foss Manufacturing OAG630	A	20	10	10	20	20	20	20	20	20	50	50	50	50	50
Ahlstrom Filtration R2817	B	20	10	10	20	20	20	20	20	20	50	50	50	50	50
Snow Filtration Style 342	C	20	10	10	20	20	20	20	20	20	50	50	50	50	50
Troy Mills Troytuf®	D	20	10	10	20	20	20	20	20	20	50	50	50	50	50
3M Company Filtrete® G0104	E	20	10	10	20	20	20	20	20	20	50	50	50	50	50

(a) Machine direction
(b) Cross machine direction
(c) Polystyrene latex particles
(d) Arizona Road Dust (fine)
(e) Silicon carbide, nominally 20 and 50 μm
(f) Compressed media
(g) Uncompressed media

Figure 1. Number of Samples Evaluated in the Matrix of Tests Performed

4.2.1 Mildew Resistance

A 21 day mildew resistance test was performed by Bowser-Morner Inc. using twenty 2" x 2" coupons per ASTM G21-70 (reapproved 1985)[1] for each material. ASTM G21-70 was selected because this method uses a mixture of organisms which are suitable for examining growth on polymeric materials. For a complete description of the test, refer to ASTM G21-70 and Bowser-Morner's report[2] in Appendix A.

4.2.2 Tensile Strength

The tensile strength test was conducted using twenty 4" x 6" samples per ASTM D1682-64 (reapproved 1975)[3] for each material. Because the materials were nonwoven, one should also reference ASTM D1117-80[4] when conducting this test for a discussion of test specimen and apparatus. This test was performed by Owens-Corning Fiberglas Corporation. Specifically, a 12-inch per minute constant rate of traverse (CRT) method was used in conjunction with the grab method to secure the specimen during a test. Samples were tested in the machine direction (MD) and cross machine direction (CMD), since some materials exhibited a directional dependence of tensile strength. These methods were selected at the recommendation of Owens-Corning. For a complete description of the test, refer to ASTM D1682-64 and Owens-Corning's report[5] in Appendix A.

4.2.3 Air Flow Resistance

The air flow resistance (pressure drop) through the filter medium was measured according to a modified version of ASTM F778-88[6]. The primary modification was to provide a means to measure pressure drop through compressed material. Detailed descriptions of the modifications and operating procedures are provided in Appendix A. Twenty 10.1-cm diameter samples of each material were tested at a flow rate of 85 lpm (for a face velocity of 18 cm/s) in compressed and uncompressed condition, with new samples used for each case. The flow velocity of 18 cm/s is equivalent to that of 85 lpm through a C2 canister. Filter media were tested in a compressed state to reflect their condition inside a C2 canister. The media were tested in a random order to eliminate any bias that may result from operator, or system variances. In an effort to

minimize variance associated with reading the pressure differential and operation of the system, a single operator conducted all tests.

4.2.4 Filtering Efficiency

The filtering efficiency of each material was measured according to a modified version of ASTM F1215-89[7]. That method is specific to polystyrene latex (PSL) test aerosols. This method was modified to provide a technique for measuring filtering efficiency employing larger dust particles, as well. In principle the two methods are the same, but they differ in some of the equipment requirements and measuring techniques. Twenty samples of each material were tested for filtering efficiency of ~ 1.1 μm PSL particles and ~ 5 μm aerodynamic mass median diameter (AMMD) fine Arizona Road Dust (ARD, AC Delco Spark Plug Division). New material was used for each test, and samples were tested in a random order. Tests were performed at a temperature of 72 ± 4°F, a relative humidity of 85 ± 5 percent, and at a face velocity of 18 cm/s. Complete details of the test system and methods are discussed in Appendix A.

To measure filtration efficiency over a much broader particle size range, similar tests were performed using nominally 20 and 50 μm sized particles. For these evaluations, nonspherical silicon carbide particles (Speedfam Corp., Des Plaines, IL) were used. Scanning electron microscopy (SEM) photographs of these particles, presented in Figures 2a and 2b, depict representative size distributions prior to pneumatic dispersion. These particles were further characterized using an Aerosizer (Malvern Instruments Inc., Southboro, MA) equipped with a powder disperser attachment. This dispersed the particles and immediately introduced them into the instrument sensing cell; consequently, transport losses were minimized. Results of this classification are presented in Figures 3a and 3b. These figures illustrate the normalized cumulative particle volume (mass) distribution as a function of aerodynamic diameter. The straight lines identify the aerodynamic mass median diameter (AMMD). The nominal 20 μm particles exhibited an AMMD of $\sim$ 31 μm with geometric standard deviation (σ_g) of 1.29 while the nominal 50 μm particles had an AMMD of $\sim$ 50 μm with σ_g of 1.24. These results further illustrate the size characteristics of particles employed for the filtration tests. Throughout the remainder of this report, the particle size will refer to the AMMD measured by the Aerosizer.

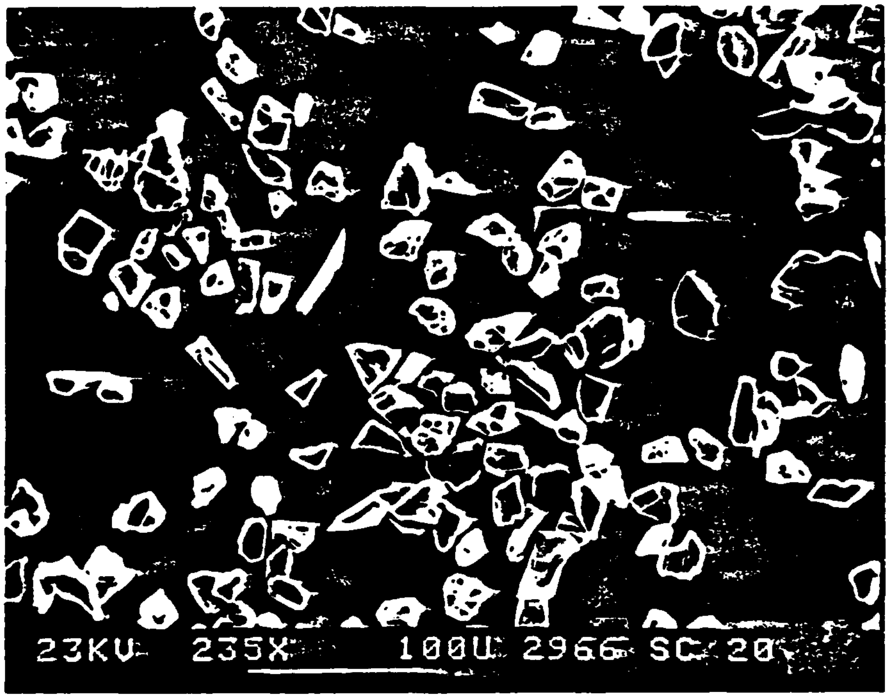


Figure 2a. Nominal 20 μm Silicon Carbide Particles Prior to Pneumatic Dispersion

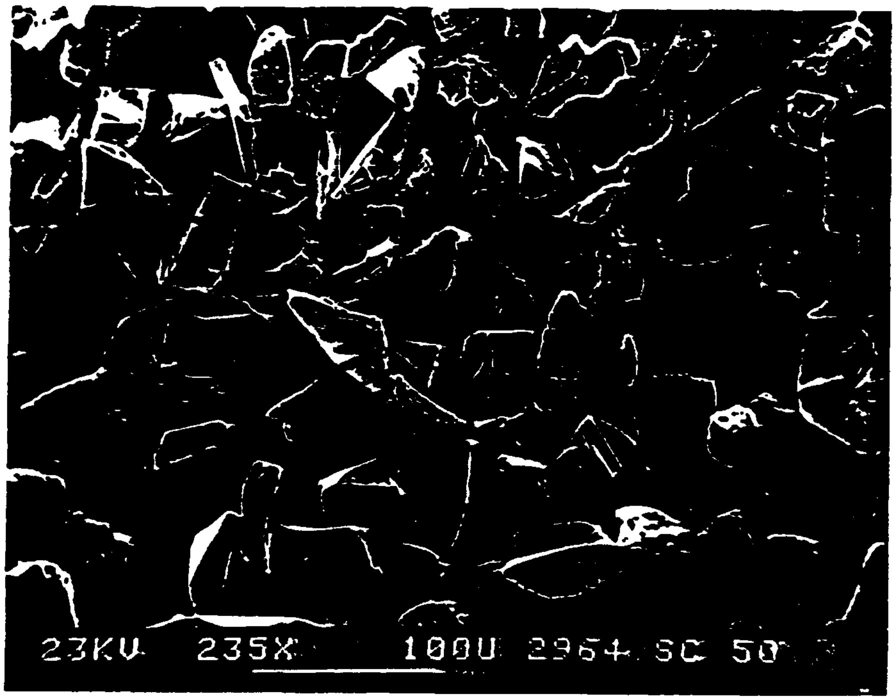
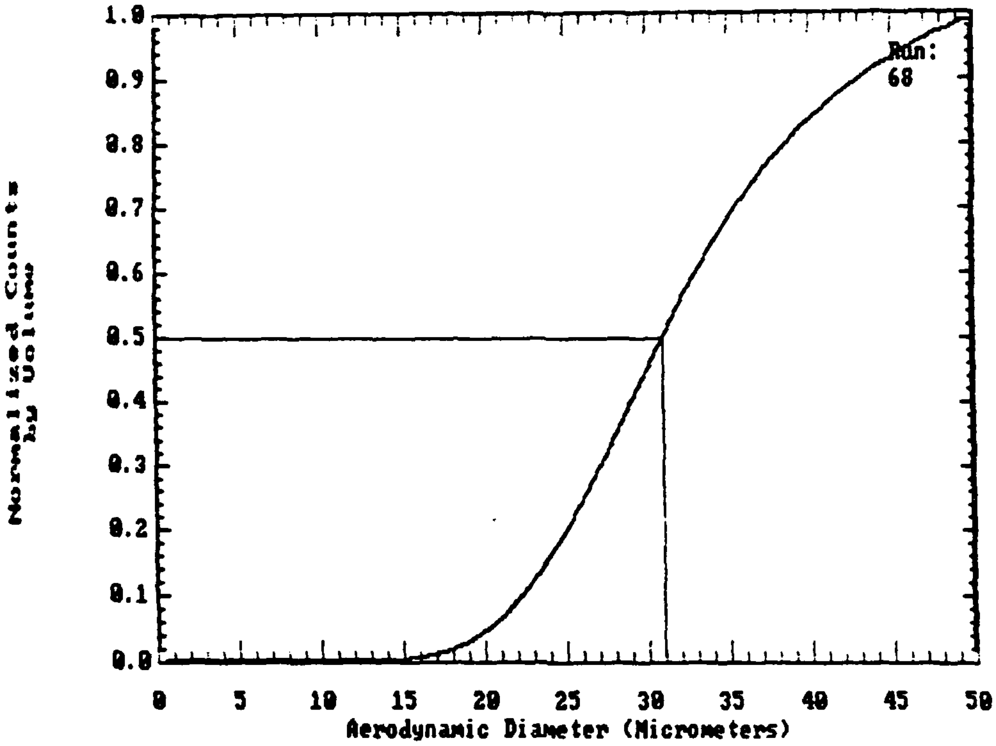
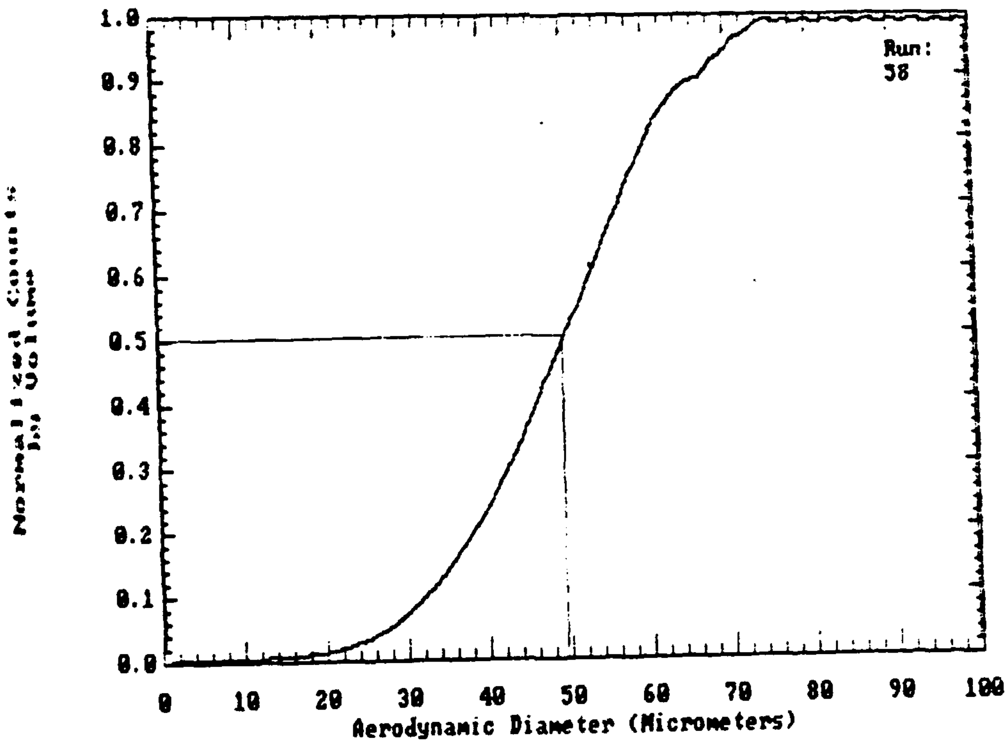


Figure 2b. Nominal 50 μm Silicon Carbide Particles Prior to Pneumatic Dispersion



(a) Nominal 20 μm Silicon Carbide



(b) Nominal 50μm Silicon Carbide

Figures 3a & 3b. Normalized Volume (Mass) Cumulative Distribution as a Function of Aerodynamic Diameter for Nominally 20 and 50 μm Silicon Carbide Particles

As in the previous two filtration tests, 20 samples of each type of medium were evaluated using both particle sizes. Details of the test method implemented are provided in Appendix A. The method is somewhat different than that conducted with ARD because of the large particle size. It becomes increasingly difficult to disperse and sample particles as the particle size increases. Test conditions were the same as those maintained during the PSL and ARD tests.

4.2.5 Manufacturer Supplied Data

Manufacturers supplied data for the following media properties: melt temperature, base weight, and thickness. In addition, they were asked to supply the methods used to determine these properties. Finally, suppliers were asked to provide a material safety data sheet (MSDS) and cost information for the media.

4.3 Prototype C2 Canister Tests

4.3.1 Air Flow Resistance

The air flow resistance of 50 test C2 canisters per each type of fines filter medium was measured by Racal Filter Technologies, Ltd.. Tests were conducted at air flow rates of 32 and 85 lpm using the Q127 DOP Filter Testing Penetrometer as specified in EA-C-1322C Amendment 6[8].

4.3.2 DOP Filtering Efficiency

The 0.3 μm DOP aerosol filtering efficiency of 50 test C2 canisters per each type of fines filter medium was measured by Racal Filter Technologies, Ltd.. Tests were conducted at air flow rates of 32 and 85 lpm using the Q127 DOP Filter Testing Penetrometer as specified in EA-C-1322C Amendment 6.

4.3.3 Canister Charcoal Volume

The canister charcoal volume was measured in eight of the C2 canisters manufactured with the current Troytuf® fines filter medium. The Q23 Container Sorbent Volumeter was used as specified in EA-C-1322C Amendment 6.

4.3.4 Charcoal Fines Emissions

The quantity of charcoal fines emitted from 50 test C2 canisters per each type of fines filter medium was determined using the Q261 shaker test, following procedures developed in previous projects performed at Battelle[9, 10]. The shaker test was performed in an environmentally controlled laboratory maintained at a target temperature of 68 ± 4°F and a relative humidity of 40 ± 5 percent. A 50 ± 5 lpm flow rate was pulled through the canisters for the 20 minute duration test. A filter downstream of the canister collected the emitted fines and the collected mass was determined gravimetrically. Canisters were tested in a random order for test canisters fabricated with OAG630, R2817, Style 342, and Troytuf® fines filter media. Canisters with the Filtrete® G0104 fines filter were tested collectively following the others because manufacturing difficulties delayed their production. One test operator conducted the test to reduce operator error, especially that associated with weighing filters.

4.4 Data Analysis

4.4.1 Baseline Tests

We performed a statistical hypothesis test to quantitatively compare performance between media types. We used the t' test statistic, because the sample size was small (less than 30) and sample standard deviations were unknown and not necessarily equal.

The null hypothesis (H_0) tested was that there is no difference between the mean property of the Troytuf® and that of the alternative media, or, H_0: $\mu_T - \mu_a = 0$. To determine if a material performed better or worse than Troytuf®, we tested the alternative hypothesis H_1: $\mu_T - \mu_a > \text{or} < 0$. The greater than or less than sign will be used to indicate that the alternative has a higher value or lower value than Troytuf®.

To perform these analyses, the sample mean $(\bar{x})$ and sample standard deviation (s) are calculated for each material type for a given test. Based upon these values, the t' test statistic is calculated as:

$$t' = \frac{(\bar{x}_T - \bar{x}_a)}{\sqrt{s_T^2/n_T + s_a^2/n_a}} \tag{2}$$

The critical value (t_α) to which t' is compared to make the decision can be found in standard statistical tables, such as those in Reference 11. The critical value depends upon the number of degrees of freedom (ν) and the level of significance (α). The degrees of freedom are calculated from:

$$\nu = \frac{(s_T^2/n_T + s_a^2/n_a)^2}{\frac{(s_T^2/n_T)^2}{n_T - 1} + \frac{(s_a^2/n_a)^2}{n_a - 1}} \tag{3}$$

Acceptance or rejection of the null hypothesis is based upon t' and t_α. The critical region is defined as those values of t' for which the null hypothesis is rejected. The critical region for H_1; $\mu_T - \mu_a > 0$ is $t' > t_\alpha$ and for H_1; $\mu_T - \mu_a < 0$, $t' < -t_\alpha$. If t' is in the critical region, we reject H_0 and accept H_1 as being true. If, however, t' is not in the critical region, then the null hypothesis is accepted, meaning that there is no statistical difference between the mean value of the property for the two media at the level of significance tested.

It is important that the reader understand the interpretation of the hypothesis test. If the null hypothesis is accepted, it does not mean that the statement is true, only that there is not enough evidence to reject it. If the null hypothesis is rejected, then the alternative hypothesis, H_1, is accepted with an α level of significance or $(1 - \alpha) \times 100\%$ degree of confidence that the alternative hypothesis is true.

4.4.2 C2 Canister Tests

To compare canister performance, we use the same procedure as described above in Section 4.4.1. The only difference is how the test statistics are calculated. Since the sample size is large (n > 30), the test statistic (z) is calculated as:

$$z = \frac{(\overline{x_T} - \overline{x_a})}{\sqrt{s_T^2/n_T + s_a^2/n_a}} \tag{4}$$

The value of z for the critical region (z_α) is found in a Gaussian distribution table at α level of significance.[11]

5. RESULTS AND DISCUSSION

5.1 Baseline Tests

5.1.1 Mildew Resistance

We investigated the resistance of media to mildew growth to ensure that they do not support the growth of fungus which may present a health risk to the wearer. The scale for growth occurring on a test coupon ranged from 0 to 3, where zero indicates no growth of fungus and three indicates complete coverage of the coupon by fungus. The values one and two represent some growth and substantial growth, respectively. All test coupons had a zero growth rating, because no growth was observed on any of the media. Complete results from Bowser-Morner Inc. are presented in Appendix B.

5.1.2 Tensile Strength

Table 2 present results of the tensile strength (breaking strength) test of the media. It also lists the number of samples (n), mean breaking strength ($\bar{x}$), standard deviation (s), and the

Table 2. Summary Statistics of the Tensile (Breaking) Strength (lbf) in the Machine Direction (MD) and Cross Machine Direction (CMD)

Sample ID	Foss Manufacturing OAG630		Ahlstrom Filtration R2817		Snow Filtration Style 342		Troy Mills Troytuf®		3M Company Filtrete® G0104	
Sample Direction	MD	CMD	MD	CMD	MD	CMD	MD	CMD	MD	CMD
n	10	10	10	10	10	10	10	10	10	10
$\bar{x}$	58.8	29.6	3.59	4.26	20.9	19.2	33.3	16.8	24.2	7.56
s	5.99	4.05	0.49	0.91	1.99	0.93	3.41	2.83	3.46	1.62
t'	-11.7	-8.2	27.3	13.4	9.9	-2.6	--	--	5.9	9.0
υ	14.3	16.1	9.4	10.8	14.5	10.9	--	--	18.0	14.3
t_α	2.62	2.58	2.82	2.72	2.60	2.72	--	--	2.55	2.62
Decision[a]	R	R	R	R	R	A	--	--	R	R
Conclusion	$\mu_a > \mu_T$	$\mu_a > \mu_T$	$\mu_a < \mu_T$	$\mu_a < \mu_T$	$\mu_a < \mu_T$	$\mu_a = \mu_T$	--	--	$\mu_a < \mu_T$	$\mu_a < \mu_T$

$\alpha = 0.01$

[a] Decision made regarding acceptance (A) or rejection (R) of null hypothesis, not to accept or reject use of material.

summary statistics calculated for the hypothesis test with $\alpha = 0.01$ level of significance. The samples were divided into the machine direction and cross machine direction for analysis.

Recall that from the hypothesis test a decision is made to accept (A) or reject (R) the null hypothesis H_0: $\mu_T - \mu_a = 0$, where μ_T is the mean tensile strength of the Troytuf® and μ_a is the mean tensile strength of an alternative medium. To reject H_0 means that we are $(1 - \alpha) \times 100\%$ confident that the statement is false. Hence, there is a difference in tensile strength, and the alternative medium had a higher or lower tensile strength. If t' is negative and less than the negative of t_α, then the alternative medium has a higher tensile strength than the Troytuf®. However, if $t' > t_\alpha$, then the alternative medium has a lower tensile strength than Troytuf®. The complete data are compiled in Appendix B.

Clearly, Ahlstrom Filtration's R2817 has a significantly lower tensile strength than the Troytuf®. Only Foss Manufacturing's OAG630 had a higher tensile strength than Troytuf® in either direction. The Troytuf® showed a significant dependence (factor of two) on direction, as did the Filtrete® (factor of three) and Foss's OAG630 (factor of two). Only Ahlstrom and Snow media showed little orientation dependence on tensile strength. The small relative standard deviations (5 to 25 percent of the mean) suggest that all fabrics were fairly uniform in a given direction.

Intuitively, there is an obvious difference between the mean tensile strength of all the materials. Testing the hypothesis that there is a difference between the means supports this. Only in the case of Style 342, tested in the cross machine direction was there no significant statistical difference between the alternative medium and the Troytuf®.

5.1.3 Air Flow Resistance

Table 3 presents results from the air flow resistance tests in terms of pressure drop through the filter media for both the compressed and uncompressed conditions. This table is to be interpreted exactly as the preceding table for tensile strength. The null hypothesis tested at $\alpha = 0.01$ was that there is no difference between the air flow resistance of the Troytuf® and each of the alternative media. The alternative hypothesis was that the alternative medium had a lower or higher air flow resistance. Testing was conducted across material types within a specific state of compression; thus, results from an uncompressed state were not compared to results in the compressed state.

Table 3. Summary Statistics for the Air Flow Resistance (Pressure Drop mm H_2O) Across Materials at a Face Velocity of 18 cm/s

Sample ID	Foss Manufacturing OAG630		Ahlstrom Filtration R2817		Snow Filtration Style 342		Troy Mills Troytuf®		3M Company Filtrete® G0104	
Sample State	Comp	Uncomp	Comp	Uncomp	Comp	Uncomp	Comp	Uncomp	Comp	Uncomp
n	20	20	20	20	20	20	20	20	20	20
$\bar{x}$	0.83	0.61	0.48	0.46	0.76	0.65	0.71	0.45	0.80	0.72
s	0.08	0.06	0.05	0.09	0.07	0.06	0.08	0.05	0.11	0.10
t'	-4.35	-9.2	11.4	-0.43	-1.68	-11.5	--	--	-2.63	-10.8
ν	38	37	32	30	37	37	--	--	35	30
t_α	2.42	2.42	2.46	2.46	2.42	2.42	--	--	2.44	2.42
Decision[a]	R	R	R	A	A	R	--	--	R	R
Conclusion	$\mu_a > \mu_T$	$\mu_a > \mu_T$	$\mu_a < \mu_T$	$\mu_a = \mu_T$	$\mu_a = \mu_T$	$\mu_a > \mu_T$	--	--	$\mu_a > \mu_T$	$\mu_a > \mu_T$

$\alpha = 0.01$

[a] Decision made regarding acceptance (A) or rejection (R) of null hypothesis, not to accept or reject use of material.

The air flow resistance of all media is small, less than 1 mm H_2O, for both compressed and uncompressed cases. The Troytuf® and OAG630 media showed a significant increase, 60 and 30 percent, respectively, in pressure drop between the uncompressed and compressed state. Style 342 exhibited a marginal increase, 17 percent when compressed. Filtrete® G0104 and R2817 showed little increase, 11 and 4 percent, respectively. This is expected, based upon the fact that Troytuf® and OAG630 are the thickest, and undergo the most change when compressed. When compressed, their fiber matrix becomes much more dense, increasing their pressure drop. Filtrete® G0104 and R2817 are very thin, and compression does not appreciably change their fiber matrix; correspondingly, the data indicate little dependence of pressure drop on compression. Style 342 lies between the two extremes.

Results from the statistical analysis indicate that alternative media generally have a different air flow resistance than Troytuf®. Since the fines filter will be compressed in a canister, it makes most sense to examine those values. When compressed, Style 342, Filtrete® G0104, and Troytuf® have nearly the same air flow resistance. Medium R2817 has a lower pressure drop, and OAG630 has a higher pressure drop than Troytuf®. In reality, these differences are negligible, relative to the total air flow resistance in a C2 canister. At the test flow rate the resistance of a C2 canister is ~ 38 mm H_2O. Hence, one type of medium with an air flow resistance 0.2 mm H_2O more than Troytuf® is insignificant, representing less than 0.5 percent of the total resistance in a C2 canister.

We conducted a series of preliminary tests to characterize the test system. Here we determined the contribution of the duct and support screens on the measured pressure differential. We used this information to correct the measured pressure differential, so the pressure drop through the filter could be isolated. The system contribution was checked periodically throughout the test. The final ancillary test was to examine the effect of a slight variation in flow rate on the pressure drop. Obviously, the pressure drop increases with increasing flow rate, but the dependence over the range from 82.5 to 87.5 lpm is less than 0.05 mm H_2O. Therefore, there is little dependence of air flow resistance in the flow range that we measured.

5.1.4 Aerosol Filtering Efficiency

Table 4 presents the media filtration efficiency (%) results using ~ 1.1 μm PSL and

$\sim 5\ \mu m$ AMMD ($\sigma_g = 1.5$) ARD. Challenge concentrations were typically 300 ± 50 particles/cm^3 for the PSL and 40 ± 10 mg/m^3 for the ARD. A couple of spurious results yielded efficiencies of near zero, and these were excluded from analysis; thus, some samples only have a count of 19. These could have been the result of a poor seal in the filter holder which would result in a leak. It was not determined, however, what the reason was for the low efficiencies. Again, this table is to be interpreted as the previous similar tables. Complete results are given in Appendix B. The null hypothesis tested at $\alpha = 0.01$ level of significance was that there is no difference between the filtering efficiency of Troytuf® and any of the other media. The alternative hypothesis is that the other media have a higher or lower filtering efficiency than Troytuf®.

Results from the hypothesis test indicate that OAG630, R2817, and Style 342 have the same aerosol filtering efficiency of PSL and ARD particles, as does the Troytuf® material. The electrostatic Filtrete® demonstrated a much higher filtering efficiency, even at the high relative humidity. All media except the R2817 had statistically significantly higher filtering efficiency for ARD than PSL, as one would expect. The effect of relative humidity is unknown since we maintained a constant value (85% ± 4%) throughout the test. It was, however, not detrimental to the performance of the electrostatic material.

Summary results and statistics of measured filtration efficiency of the five media using 31 and 50 μm challenge aerosol are presented in Table 5. Challenge mass concentrations were 100 ± 25 mg/m^3 and 40 ± 10 mg/m^3. Comparison of the efficiencies between 31 and 50 μm within a material type shows that efficiency increases with increasing particle size, as expected. Three of the media, Filtrete® G0104, OAG630, and Style 342, all exhibited a consistent increase in efficiency with increasing particle size. All three of these media provided efficiencies of 87 to 95 percent for the 50 μm particles; 78 to 88 percent with 31 μm particles. Note that the beneficial electrostatic effect on filtration has been at least partially lost because the electrical mobility of the particles is becoming too small to significantly affect filtration. Particle size dependence was not as apparent for the Troytuf® and R2817 media. The Troytuf® medium had an average efficiency of 46 percent with the 50 μm particles. For these two media, the filtration efficiency is not much higher than that measured for the smaller particles. The hypothesis tests corroborate what is intuitive, that the Filtrete® G0104, Foss OAG630, and Snow Style 342 are substantially better filters of 31 and 50 μm particles than is the Troytuf® medium. Alhstrom's R2817 is less efficient at filtering these particles.

Table 4. Summary Statistics of the Filtering Efficiency (%) of 1.1 μm Polystyrene Latex (PSL) and ~ 5 μm AMMD fine Arizona Road Dust (ARD) Particles for the Five Media

Sample ID	Foss Manufacturing OAG630		Ahlstrom Filtration R2817		Snow Filtration Style 342		Troy Mills Troytuf®		3M Company Filtrete® G0104	
	PSL	ARD	PSL	ARD	PSL	ARD	PSL	ARD	PSL	ARD
n	20	19[a]	20	20	19[a]	20	20	20	20	19[a]
$\bar{x}$	29	38	35	39	25	37	27	39	53	66
s	13	9	16	11	15	12	13	13	11	9
t'	-0.46	0.23	-1.83	0.05	0.44	0.46	--	--	-6.88	-7.67
ν	38	34	37	37	35	38	--	--	37	34
t_α	2.42	2.44	2.42	2.42	2.44	2.42	--	--	2.42	2.44
Decision[b]	A	A	A	A	A	A	--	--	R	R
Conclusion	$\mu_a=\mu_T$	$\mu_a=\mu_T$	$\mu_a=\mu_T$	$\mu_a=\mu_T$	$\mu_a=\mu_T$	$\mu_a=\mu_T$	--	--	$\mu_a>\mu_T$	$\mu_a>\mu_T$

$\alpha = 0.01$

[a] Spurious datum was eliminated from analysis

[b] Decision made regarding acceptance (A) or rejection (R) of null hypothesis, not to accept or reject use of material.

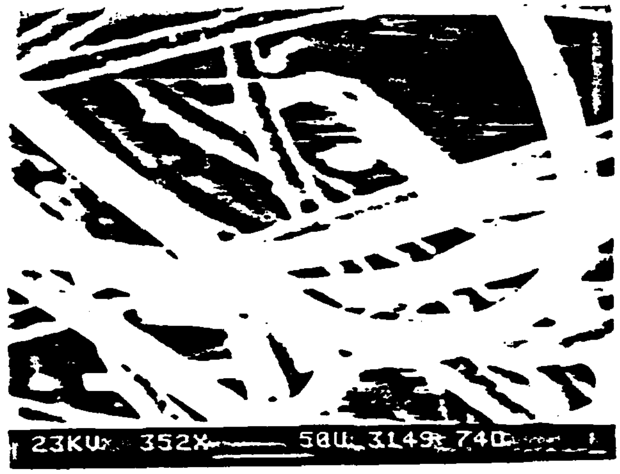
The relatively low efficiencies for these media, even when filtering large particles, is not surprising considering the media's fiber matrices. SEM photographs of all test media and a glass fiber absolute filter after filtration of 31 μm particles are depicted in Figures 4a through 4f. It is evident that Ahlstrom's R2817 and Troytuf® have poor filtering capabilities; there are no particles visible on the leading surface of fibers. Particles may have been collected deeper within the Troytuf® filter which would not be visible with SEM because of its limited depth of field. One can also see the extremely porous fiber matrix. It is common to observe distances of 100 μm between fibers. The fiber matrix of the media do not appear to be substantially different. It is clear by the number of particles seen, however, that these three media are able to capture and retain the particles more efficiently. Finally, for comparison, 31 μm particles collected on a high efficiency glass fiber filter are shown. Obviously the high efficiency (and, thus, relatively high airflow resistance) is a result of the thinner fibers and denser fiber matrix. These photographs provide visual evidence that the 31 μm particles dispersed are being sampled and transported to the filter element. The same observations were made when viewing media after collecting 50 μm particles.

5.1.5 Manufacturer Supplied Data

Several properties of interest were determined by the manufacturer through standard tests. The fabric suppliers were asked to provide melt temperature, base weight, thickness, and the method used to determine them and cost. Their input is given in Table 6.

The manufacturers used many different methods to evaluate the same material properties. Brief comments of these methods are given and the interested reader is referred to the reference for a complete discussion. All manufacturers reported melting temperature as the melting point of the pure polymer, since their fibers are 100 percent polyester or polypropylene. However, we were able to find a standard method for determining melt temperature. A section in ASTM D276[12] "Standard Test Methods for Identification of Fibers in Textiles" contains a brief description of a method for determining fiber melting point. The detailed procedure for measuring base weight is documented in ASTM D3776[13] "Mass Per Unit Area (Weight) of Woven Fabric". ASTM D461[14] "Standard Test Methods for Felt" and D2646[15] "Standard Test Methods for Backing Fabrics" give a terse description of the method for measuring base weight. ASTM D461 gives a very brief description for measuring thickness; however, a better, more detailed, discussion of procedures for

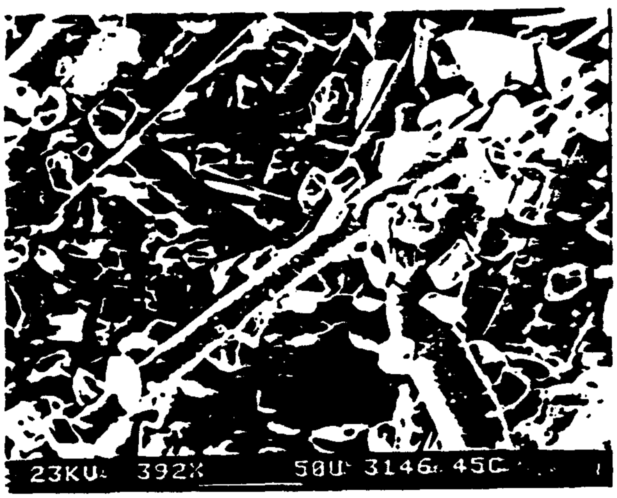
(a) 3M Filtrete® G0104



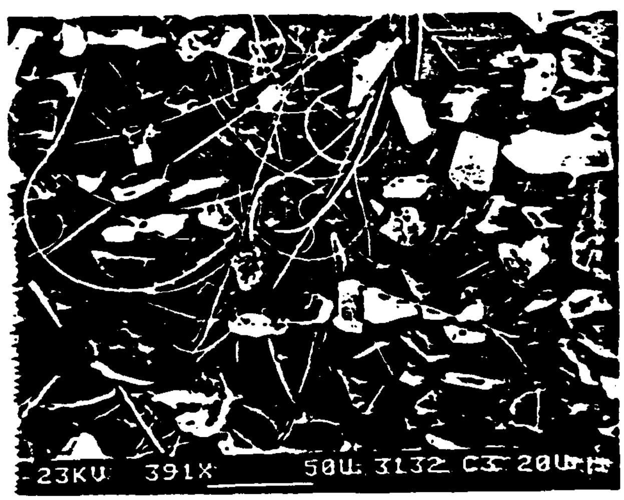
(b) Troy Mills Troytuf®

(c) Ahlstrom Filtration R2817

(d) Foss Manufacturing OAG630



(e) Snow Filtration Style 342



(f) Glass Fiber Filter

Figure 4a - f. Collection of 31 μm Silicon Carbide Particles During Filtration Efficiency Test of Each Fines Filter Medium and on a Glass Fiber Absolute Filter.

Table 5. Summary Statistics of the Filtering Efficiency (%) of 31 μm and 50 μm Silicon Carbide Particles for the Five Media.

Sample ID	Foss Manufacturing OAG630		Ahlstrom Filtration R2817		Snow Filtration Style 342		Troy Mills Troytuf®		3M Company Filtrete® G0104	
	31 μm SC	50 μm SC	31 μm SC	50 μm SC	31 μm SC	50 μm SC	31 μm SC	50 μm SC	31 μm SC	50 μm SC
n	20	20	20	20	20	20	20	20	20	20
$\bar{x}$	81	87	29	36	88	95	38	46	78	90
s	8	8	11	15	4	3	8	9	9	7
t'	-17	-15	2.96	2.56	-25	-23	--	--	-15	-17
ν	38	37	35	31	28	23	--	--	37	36
t_α	2.42	2.42	2.44	2:45	2.47	2.50	--	--	2.42	2.43
Decision[a]	R	R	R	R	R	R	--	--	R	R
Conclusion	$\mu_a > \mu_T$	$\mu_a > \mu_T$	$\mu_a < \mu_T$	$\mu_a < \mu_T$	$\mu_a > \mu_T$	$\mu_a > \mu_T$	--	--	$\mu_a > \mu_T$	$\mu_a > \mu_T$

$\alpha = 0.01$

[a] Decision made regarding acceptance (A) or rejection (R) of null hypothesis, not to accept or reject use of material.

Table 6. Melt Temperature, Base Weight, Thickness and Cost of the Five Media and the Test Methods Used by the Manufacturer

	Foss Manufacturing OAG630	Ahlstrom Filtration R2817	Snow Filtration Style 342	Troy Mills Troytuf®	3M Company Filtrete® G0104
Melt Temperature (C)	252-255	252	252	255	170
Method	MP of polyester	MP of polyester	MP of polyester	MP of polyester	MP of polypropylene
Base Weight (g/m^2)	100	51	110	77	40
Method	ASTM D2646-69	ASTM D646-86	ASTM D1910	ASTM D461-72	(b)
Thickness, (mm)	2.3	0.3	1.7	1.9	(a)
Method	ASTM D1777-64	ASTM D645-67	ASTM D1777-64	ASTM D461-72	(b)
Cost	$0.397/yd^2	$0.507/lineal yd, 30" wide roll	$1.10/lineal yd, 54" wide roll	$0.71/lineal yd, 40" wide roll	(b)

(a) Test not performed

(b) Not supplied by manufacturer

measuring thickness is found in D1776[16] "Measuring Thickness of Textile Materials". Ahlstrom Filtration used ASTM D646-86[17] "Grammage of Paper and Paperboard (Weight Per Unit Area)" and D645-67 (since discontinued) for their methods. These two methods are associated more with the paper industry and would not be applicable for materials such as Troytuf®.

5.2 C2 Test Canister Results

Even though there were some substantial performance differences between the Troytuf® and some of the alternative media from the baseline tests, it was decided that 50 prototype C2 canisters of each type would be fabricated per EA-C-1322C Amendment 6 for further testing.

Racal Filter Technologies, Ltd., encountered a manufacturing difficulty during production of test canisters employing the 3M Filtrete® medium. This medium has a ¼" x ¼" rigid plastic support grid. Normally, the fines filter disk is slightly oversized and the edges curl up along the walls of the cylindrical metal housing of the canister. This is performed to provide an "edge seal" along the canister wall. When this was attempted with the Filtrete® medium, the rigid support would not flex to conform to the canister wall, but rather form gaps. Consequently, coarse charcoal can pour through channels along the wall. Because the usual oversized disks were not usable, Racal cut smaller discs so they were the inner diameter of the canister. These discs had a tendency to curl and would not lay flat which presented a problem when trying to fill with charcoal. Racal decided to heat press the discs for ~ 2 hour at 110°C. The discs shrank about ¼" in diameter, but still covered the bottom. Filtration experts at 3M Company indicated that such a procedure would lessen the electrostatic charge by some unknown degree. They do not recommend heating over 70°C for any length of period. Finally, the fabrication step to heat weld the fines filter medium to a plastic support grid was not possible because of the lower melting temperature of the polypropylene material.

5.2.1 Air Flow Resistance

Racal Filter Technologies, Ltd., conducted air flow resistance tests at 32 and 85 lpm on C2 test canisters. The 85 lpm flow corresponds to an air velocity of 18 cm/s. Table 7 gives summary results in terms of a pressure drop (mm H_2O). Once again, this table is similar to previous ones and interpreted in the same manner. Note, however, the new test statistic, z. The usual null hypothesis that there is no difference between the mean air flow resistance of Troytuf® and the

Table 7. Summary Statistics of Air Flow Resistance (mm H_2O) of C2 Test Canisters Fabricated with Each Type of Fines Filter Medium at Flow Rates of 32 and 85 LPM

	Foss Manufacturing OAG630		Ahlstrom Filtration R2817		Snow Filtration Style 342		Troy Mills Troytuf®		3M Company Filtrete® G0104	
	32	85	32	85	32	85	32	85	32	85
n	50	50	50	50	50	50	50	50	50	50
$\bar{x}$	13.3	38.7	12.8	34.9	12.8	37.3	13.6	37.9	14.7	45.6
s	0.3	1.1	0.4	1.1	0.3	0.9	0.4	1.2	0.7	2.4
z	4.85	-3.57	11.2	12.71	11.5	2.51	--	--	-9.19	-20.11
z_α	2.33	2.33	2.33	2.33	2.33	2.33	--	--	2.33	2.33
Decision[(a)]	R	R	R	R	R	R	--	--	R	R
Conclusion	$\mu_a < \mu_T$	$\mu_a > \mu_T$	$\mu_a < \mu_T$	$\mu_a < \mu_T$	$\mu_a < \mu_T$	$\mu_a < \mu_T$	--	--	$\mu_a > \mu_T$	$\mu_a > \mu_T$

$\alpha = 0.01$

(a) Decision made regarding acceptance (A) or rejection (R) of null hypothesis, not to accept or reject use of material.

alternative medium was tested against the alternative hypothesis that alternative canisters have a lower or higher air flow resistance than Troytuf® canisters. Statistical tests were conducted at $\alpha = 0.01$ level of significance.

Results from the statistical analyses indicate that R2817 and Style 342 have a lower air flow resistance than Troytuf® at both flow rates. The OAG630 medium has a lower resistance at 32 lpm and a higher resistance at 85 lpm than Troytuf®. Filtrete® G0104 has a higher air flow resistance than Troytuf® at both flow rates. Because of a production problem employing Filtrete®, the material was heat pressed. This process resulted in the fibers shrinking, hence changing the fiber matrix so that the fibers are more densely packed. This may contribute to the somewhat higher pressure drop across the canister. These pressure drop measurements cannot, therefore, be related to the original material tested in the baseline test.

While, statistically, the canisters differ in air flow resistance, practically the difference would be unnoticed. In all cases except the Filtrete® G0104 at 85 lpm, the relative difference between Troytuf® type canisters and the other canisters is less than 10 percent, or less than 3 mm H_2O. There is no good correlation between the baseline test pressure drop measurements and those for canisters. For instance, Foss manufacturing's OAG630 medium had a higher airflow resistance than Troytuf®. It is not clear why there is no good correlation.

Results for all types of canisters fall within the 10 to 18 mm H_2O air flow resistance range when tested at an air flow rate of 32 lpm established in EA-C-1322C Amendment 6.

5.2.2 DOP Aerosol Filtering Efficiency

Table 8 presents summary results from the DOP aerosol filtering efficiency in terms of percent penetration of prototype C2 canisters. Racal Filter Technologies, Ltd., conducted tests at 32 and 85 lpm on all five types of C2 test canisters. The interpretation of this table is exactly as that for the previous air flow resistance table. The null hypothesis tested was that there was no difference between mean percent penetration of Troytuf® type canisters and that of canisters fabricated with alternative fines medium. The alternative hypothesis was that there was a difference and that the difference was lower percent penetration or higher percent penetration. Statistical tests were conducted at $\alpha = 0.01$ level of significance.

Table 8. Summary Statistics of DOP Aerosol Percent Penetration (%) of C2 Test Canisters Fabricated with Each Type of Fines Filter Medium at Flow Rates of 32 and 85 LPM

	Foss Manufacturing OAG630		Ahlstrom Filtration R2817		Snow Filtration Style 342		Troy Mills Troytuf®		3M Company Filtrete® G0104	
	32	85	32	85	32	85	32	85	32	85
n	50	50	49[a]	49[a]	50	50	50	50	50	50
$\bar{x}$	.0009	.0029	.0016	.0032	.0008	.0027	.0016	.0026	.0014	.0063
s	.0007	.0014	.0013	.0015	.0011	.0012	.0006	.0010	.0004	.0017
z	5.82	-0.99	0.10	-2.36	4.48	-0.40	--	--	2.19	-13.0
z_α	2.33	2.33	2.33	2.33	2.33	2.33	--	--	2.33	2.33
Decision	R	A	A	R	R	A	--	--	A	R
Conclusion	$\mu_a < \mu_T$	$\mu_a = \mu_T$	$\mu_a = \mu_T$	$\mu_a > \mu_T$	$\mu_a < \mu_T$	$\mu_a = \mu_T$	--	--	$\mu_a = \mu_T$	$\mu_a > \mu_T$

$\alpha = 0.01$

(a) One spurious datum with a high percent penetration was eliminated from analysis

(b) Decision made regarding acceptance (A) or rejection (R) of null hypothesis; not decision regarding use of material

These results show that the filter efficiency of the canister is nearly the same or somewhat better when OAG630, R2817, and Style 342 were used, compared to the Troytuf® type canisters. This is also true at 32 lpm with the Filtrete® type canisters; however, at 85 lpm the Filtrete® type canisters perform worse. This result may not be due to higher aerosol penetration but may be a result of the inability of the Filtrete® fines filter to retain charcoal fines. The fines filtering ability will be discussed later.

Racal uses a Q127 tester to measure particle concentration for the filtering efficiency test. The photometer incorporated in that device cannot count the number of particles nor size the particles. The amount of scattered light it detects is a function both of particle size and of number concentration. Consequently, the photometer cannot distinguish between the size specific DOP particles which penetrate and any carbon particles that shed from the charcoal bed.

From a practical viewpoint, differences in apparent aerosol penetration are negligible. In terms of percent efficiency, the values range from 99.9970 to 99.9992, excluding Filtrete® data at 85 lpm. These results are also consistent with what one expects. The primary aerosol filtration media are the same in all canisters and the fines media are not intended to filter the challenge aerosol. Thus, there is no reason to expect the apparent measured DOP aerosol filtering efficiency to differ for canisters with different fines media.

Results for all types of canisters are below the specified maximum penetration of 0.010 percent using a smoke concentration of 100 μg/l, an average particle diameter of 0.3 μm, and a flow rate of 32 lpm as required by EA-C-1322C Amendment 6.

5.2.3 Charcoal Canister Volume

The charcoal volumes measured for eight C2 canisters fabricated with the Troytuf® fines filter medium are: 170, 172, 174, 174, 174, 172, 174, and 174 cm^3. The average volume is 173 cm^3 with a standard deviation of 1.5 cm^3. These values are within the 175 $\pm$ 5 cm^3 range specified in EA-C-1322C Amendment 6.

5.2.4 Charcoal Fines Emissions

Table 9 gives summary statistics for the quantification of charcoal fines emitted during the Q261 shaker test in milligrams. Tests were conducted for 20 min at flow rates of 50 ± 5 lpm. The table is interpreted exactly as the prior tables. The null hypothesis tested was that there is no difference between the mean mass of charcoal fines emitted from a C2 canister employing Troytuf® fines filter and from C2 canisters with an alternative medium. The alternative hypothesis was that the alternative media were better or worse than the Troytuf® at retaining charcoal fines. The complete results are contained in Appendix B.

Results from the statistical hypothesis test show there is no difference between canisters fabricated with Troytuf® and those fabricated with OAG630, R2817, and Style 342 fines filters. However, there is significantly more mass emitted from canisters that contain Filtrete® for the fines filter. As stated earlier, the Filtrete® material was heat pressed during canister fabrication. According to 3M Company filtration specialists, this will definitely reduce the electrostatic charge; and thereby reduce its filtering capabilities. The extent to which it is affected is unknown. From the independent filtering efficiency test conducted in the baseline tests, the Filtrete® should be capable of retaining the charcoal fines better than demonstrated, but the manufacturing difficulty would need to be solved before it could be used.

The results for OAG630, R2817, Style 342, and Troytuf® all meet the charcoal fines emissions performance specification established in EA-C-1322C Amendment 6. The requirement is that the average emissions from 50 canisters is less than 2 mg and that any one canister does not exceed 5 mg. In fact for these four canister types none exceeded 2 mg. The Filtrete® type canisters did meet the performance criteria, but clearly did not perform as well as the other canisters.

6. CONCLUSIONS AND RECOMMENDATIONS

The results of these tests indicate that alternative media are commercially available that are acceptable as replacements for the Troy Mills Troytuf® fines filter medium in the C2 canister. Furthermore, these media are competitively priced.

The results from the baseline tests for air flow resistance and filtering efficiency corresponded to results obtained in the C2 canister tests. That is, if the air flow resistance test

Table 9. Summary Statistics of Charcoal Fines Emissions (mg) of C2 Test Canisters Fabricated with Each Type of Fines Filter Medium

	Foss Manufacturing OAG630	Ahlstrom Filtration R2817	Snow Filtration Style 342	Troy Mills Troytuf®	3M Company Filtrete® G0104
n	50	50	50	50	50
$\bar{x}$	0.528	0.570	0.516	0.575	0.925
s	0.248	0.230	0.269	0.324	0.663
z	0.82	0.09	0.99	--	-3.35
z_α	2.33	2.33	2.33	--	2.33
Decision[(a)]	A	A	A	--	R
Conclusion	$\mu_a = \mu_T$	$\mu_a = \mu_T$	$\mu_a = \mu_T$	--	$\mu_a > \mu_T$

$\alpha = 0.01$

(a) Decision made regarding acceptance (A) or rejection (R) of null hypothesis; not decision regarding use of material.

demonstrates a resistance near that of Troytuf®, one can expect little difference in canister air flow resistance. Likewise, the baseline test for filtering efficiency of particles less than 5 μm yielded comparable results between media, and the charcoal emissions from the canister with different fines media were similar. However, there were differences between measured filtration efficiencies for the 31 and 50 μm particles, yet no significant differences in charcoal emissions. These particle sizes may not be representative of the charcoal fines particles; hence, the differences in filtration efficiency for large particles was not important in how well charcoal fines were retained during shaker testing. This was the case for the media we tested, except for Filtrete®. Because of the heat pressing during fabrication, the Filtrete® fines filter performance in the canister cannot be compared to the Filtrete® performance from the baseline tests.

Comments from the C2 canister fabricators indicate that media that are significantly different in physical properties than the Troytuf® may require modifications in the canister production process. If no such changes are desired, then we would recommend selecting alternative media that are similar to Troytuf®. This category would include nonwoven, needle punched polyesters, like Foss Manufacturing's OAG630 and Snow Filtration's Style 342 tested in this project.

Evaluation of other alternative media's acceptability can be performed using the procedures followed in this project and set forth in the draft Military Specification submitted separately. The results of this work can therefore be used to select replacements for the currently sole-source item used for C2 fines filtration.

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APPENDIX A

TEST METHODS AND OPERATING PROCEDURES

Baseline Tests

- Mildew Resistance: Bowser-Morner Report
- Tensile Strength: Owens-Corning Fiberglas Report
- Air Flow Resistance: Modifications to ASTM F778-88
- Filtering Efficiency: Modifications to ASTM F1215-89

C2 Canister Tests

- Charcoal Fines Emission

Mildew Resistance Test

The attached text from Bowser-Morner's Report supplements ASTM G21-70 and further describes the procedures and test system that they followed.

Lab. Report No. 9008326-001 Date: September 26, 1990

Report of Fungus Resistance Test on
Five (5) Sets of Twenty (20) 2" x 2" Test Coupons.

For

Battelle Laboratories
505 King Avenue
Columbus, Ohio 43201-2693

BOWSER-MORNER, INC.
Product & Materials Testing Laboratory
Analytical Sciences Division

Client's Order No.: W9949

Prepared by: Richard J. Hardin Date 28-Sept-90
Richard J. Hardin
Senior Engineering Technician

Approved by: Robert J. Rosencrans Date 28-Sept-90
Robert J. Rosencrans, Manager
Product & Materials Testing Lab.

Appendix A

FACTUAL DATA

SECTION I - LIST OF APPARATUS:

Item	Manufacturer	M/N	S/N	Range	Accuracy	BMI No., Last Calibration Date and Next Calibration Date Per MIL-STD-45662A
Fungus Chamber	Tenney Engineering, Inc.	TH-27	E52176	Ambient to 100°F	±1°F	BMI No. 2547 November-14-1989 November-14-1990
Temperature Controller Recorder	Honeywell	602C41DD-24-75	810989	0° to 100°F	±0.5°F	BMI No. 2547 November-14-1989 November-14-1990
Fungus Spores	Belmonte Park Laboratories	ASTM G21-70	Para. 6.4.1	N/A	N/A	BMI No. 9008326 September-5-1990 Per Test
Medical Gloves	Becton Dickinson	102223	None	7 1/2-8	N/A	BMI No. None N/A N/A
Control Samples	BOWSER-MORNER, INC.	ASTM G21-70	PARA. 7.1	N/A	N/A	BMI No. None N/A N/A

FACTUAL DATA

SECTION II - TEST PROCEDURES:

A description of the test procedures utilized in conducting the Fungus Resistance Test on Five (5) Sets of Twenty (20) 2" x 2" Test Coupons is as follows:

The Five (5) Sets of Twenty (20) 2" x 2" Test Coupons were placed into the fungus chamber with gloved hands. Three (3) viability control samples of one (1) inch square filter paper on hardened nutrient-salt agar in Petri dishes were also placed in the Fungus Chamber. The Chamber temperature was set and maintained at 84°±2°F and 85% or greater relative humidity per ASTM G21-70. The Test Coupons and Control Samples were inoculated by use of an atomizer with a mixture of fungus spores containing the following organisms:

Aspergillus Niger
Gliocladium Virens
Aureobasidium Pullulans
Penicillium Funiculosum
Chaetomium Globosum

The spore suspension was cultured and prepared in accordance with ASTM G21-70 (Reapproved 1980).

The test chamber was maintained at a temperature of 84°±2°F (29°±1°C) and a relative humidity of 85% or greater throughout the test.

The Control Samples were inspected for increased growth of fungus spores each week. The test Coupons were subjected to these conditions for a period of 21 days minimum per ASTM G21-70. The Test Coupons and Control Samples were visually examined for evidence of Fungus growth after the twenty-one (21) days incubation.

The Test Coupons were disposed of properly at the completion of the test per Client's instructions.

Tensile Strength Test

Attached is a portion of Owens-Corning Fiberglas' report which further describes the method and procedures they used for tensile strength per ASTM D1682-64.

OWENS-CORNING FIBERGLAS

OWENS-CORNING TESTING SERVICES

OWENS-CORNING FIBERGLAS CORPORATION

TECHNICAL CENTER, 2790 Columbus Rd.
Granville, OH 43023-1200. (614) 587-7023

October 1, 1990

Kent C. Hofacre
Battelle
Environmental Chemistry & Physics Dept.
505 King Avenue
Columbus, OH 43201-2693

<u>TEST REPORT</u> 48708

<u>TEST REQUESTED</u> Breaking Strength

<u>SAMPLE DESCRIPTION</u>

The customer supplied five various fabric swatches approximately two feet square, identified as A, B, C, D and E. No other description was supplied.

Conditioning: 70 +/-2 degrees F, 50 +/-5% R.H.

<u>TEST PROTOCOL</u>

The customer requested breaking strength per ASTM Test Method D1682. Twenty specimens were to be broken for each submitted sample for a total of 100 specimens. The specimens were to be tested in random order. A SAS RANDOM number sequence was established for the 100 specimens and tested accordingly. A 20+/-3 second time to break criteria is usual. However, since the samples exhibited varying strain characteristics and specimens were to be broken in a random order, a constant speed of 12 inches per minute was selected. The 1-inch Grab strength procedure was selected since 4 of the 5 fabrics were the nonwoven type. The clamping jaw consisted of a 1 x 3 inch back face and a 1 x 1 inch front face, rubber faced and air actuated. Specimens were cut 4 x 6 inches with the long direction parallel to the load

application. Gage length was set to 3 inches. Individual tests were conducted on an Instron 4202 tensile tester with computer interface.

RESULTS OF TESTS

Individual and average values are shown on the attachments. The machine direction was assumed to be represented by the direction having the lowest elongation and generally the highest strength. Average values are presented with respect to sample and direction. Although not requested, values for elongation at peak load are included.

NOTE: Owens-Corning Testing Services makes no warranty, express or implied, whether of merchantability or fitness for any particular purpose, with respect to the test performed, other than that the tests have been performed in accordance with the current standard techniques.

R A Casper

Signed: R. A. Casper
IMG Testing Laboratory

G. L. Williams

Approved: G. L. Williams, Mgr.
IMG Testing Laboratory

RAC/sc

Attachments: 3

Air Flow Resistance

The ensuing text describes the test apparatus and procedure used for testing the air flow resistance of compressed and uncompressed material, and is intended to supplement ASTM F778-88, Method A, Case 1. The reader is referred to ASTM F788-88 for complete details of the procedures used.

A schematic of the air flow resistance test apparatus is presented in Figure A-1. Figure A-1 is a detailed representation of Figure 2 in Section 12 of ASTM F778-88. This apparatus was used for both the compressed and uncompressed tests. The apparatus comprises an upstream and downstream duct, flow meter, pneumatic cylinder, flow straightening device, inclined manometer, blower, and specimen holder. Air enters the upstream duct after passing through the dry gas meter, passes through a flow straightening device, through the test medium, through another flow straightener and is exhausted at the blower.

The separate upstream and downstream ducts are each 1 meter long and 10.1 cm inside diameter. Each has a flow straightening device half way down the duct. The downstream duct has a variable speed blower sealed to the end to draw air through the system at 85 lpm to produce a 18 cm/s face velocity through the material. A collar is sealed to the downstream duct so when the two ducts are forced together they seal around the material holder. The inlet of the upstream duct is sealed with a metal cap which has a 2.5 cm opening for the inlet air. The air inlet is connected to a dry gas flow meter to measure the flow rate. Also affixed to this cap is a stationary pneumatic cylinder used to force the ducts together.

Between the two ducts is the mechanism for compressing and supporting the test material. At the end of each duct is a rubber O-ring. Next is a metal ring with the same inner and outer diameter as the PVC duct. On the down stream side, this ring has a nichrome mesh screen reinforced with 1/16" stainless steel rod for support on the backside. The screen is a 10 x 10 meshes per linear inch with 0.075 in. opening and a wire diameter of 0.025 in. This serves as the support screen. The metal ring for the upstream side is identical to the downstream and serves as the compression screen. For tests that do not require compression, a metal ring without the screen is used on the upstream side. Between the two rings is the test material. A stationary pneumatic cylinder with a 3" bore affixed to the upstream metal cap was operated at 50 psig to compress the ducts together with a force of ~360 lbf. If the compression screen is in place then the 360 pounds of force is distributed over the 11.4 cm screen resulting in a pressure of 23 psi, which is representative

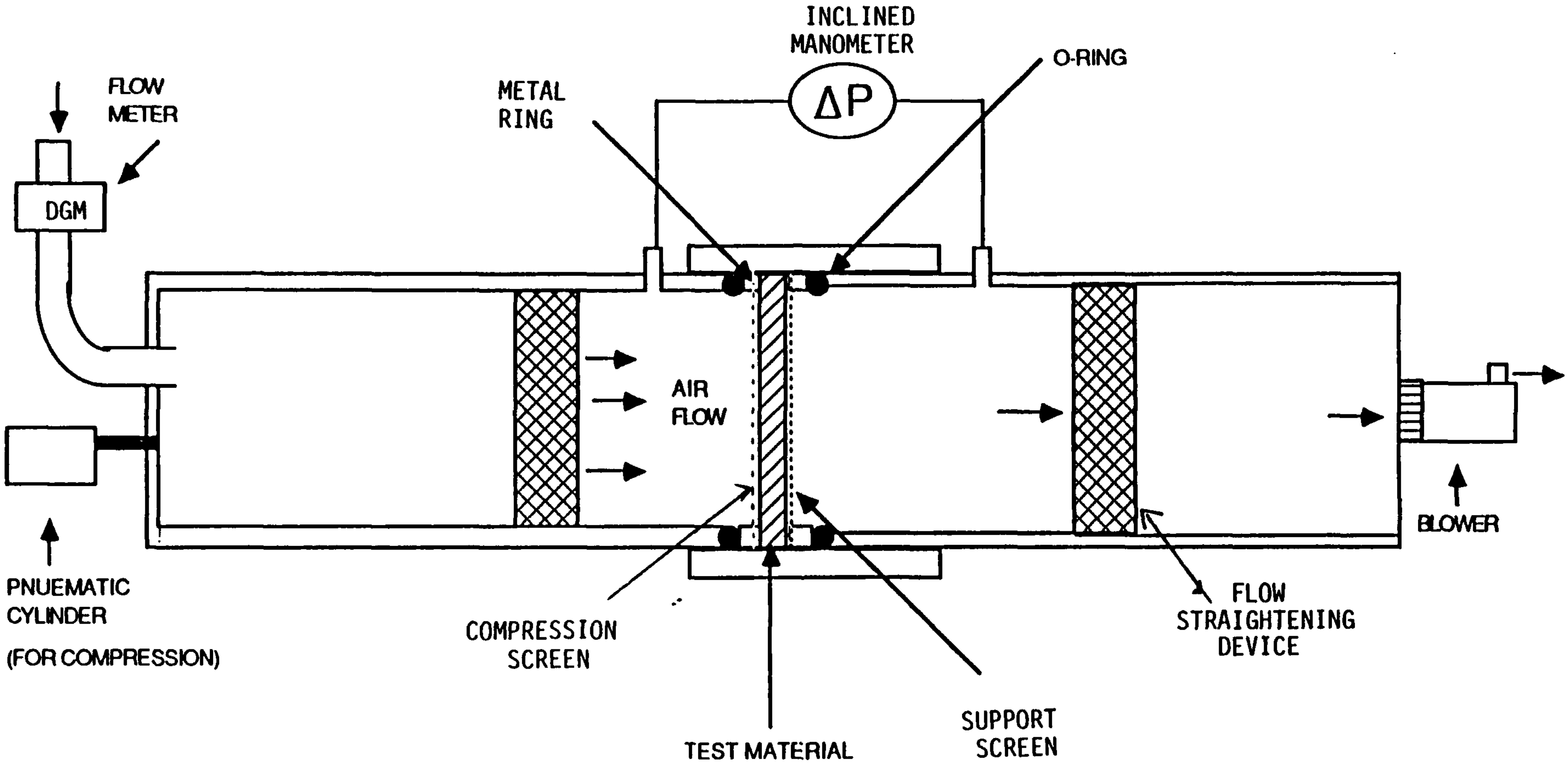


FIGURE A-1. AIR FLOW RESISTANCE TEST APPARATUS

of the pressure on a fines filter in a canister. If the metal ring without a screen is used upstream then only the outer 6 mm of the material is compressed and the remainder is uncompressed. The O-rings seal around the collar and the metal rings so air is forced to flow through the test material and not leak around the edges. The material is always supported by the back side screen.

The pressure drop over the material was measured by an inclined manometer. A pressure tap was located 5 cm upstream of the filter and four taps were located downstream: 5, 10, and two 15 cm from the filter. The two taps 15 cm downstream were located 90° from each other. The reason for four downstream pressure taps was to see if there was any dependence of ΔP on location. All pressure ports were flush with the duct wall. Preliminary tests indicated that the pressure drop through the material was not dependent upon the downstream port used; therefore, data were collected at the tap located 15 cm downstream.

A test was conducted by retracting the upstream portion of duct with the pneumatic cylinder and placing the 11.4 cm circular disk of material against the back support screen. The open ring or compression screen was inserted and the two ducts compressed together with a force of ~360 lbf. The flow rate through the medium was adjusted to 85 lpm and recorded. Finally, after 2 minutes were given to allow the inclined manometer to stabilize, the pressure differential was measured.

Procedure for Measuring Aerosol Filtration Efficiency

This procedure describes the method used to determine the filtering efficiency of the media. The method is divided into three sections: one for the polystyrene latex (PSL), one for the Arizona Road Dust (ARD, AC Delco Spark Plug Division) and one for 31 and 50 μm silicon carbide particles. The different particle sizes require two separate methods because of the differences in the sampling and analysis technique used. This description supplements the general procedures in ASTM Method F1215-89 which has been modified to provide a method to test using ARD and silicon carbide particles.

PSL

A schematic of the filter efficiency test apparatus for the PSL aerosols is shown in Figure A-2. Figure A-2 is a detailed representation of the schematic shown in Figure 1 of ASTM F1215. The system comprises an aerosol generator, humidifier, upstream chamber, filter holders, downstream chamber, and a particle counter. The chambers provide a plenum for sampling upstream and downstream concentrations, eliminating the need for isokinetic sampling in a flowing air stream.

A nebulizer operated with filtered, regulated house air was used to generate 300 ± 50 particles/cm^3 of 1.1 μm PSL aerosol from a water suspension. The aerosol was generated and transported to a 220 l (60cm x 60cm x 60cm) upstream chamber where it was mixed by fans with an air conditioning stream. Flow rates of the conditioning and nebulizer air streams were regulated to maintain a relative humidity of 85 ± 4 percent, a temperature of 72 ± 4°F, and a particle concentration of approximately 300 particles per cubic centimeter. The total air flow rate into the upstream chamber was 30 lpm. Excess air was vented through the exhaust filter so a continuous, steady state aerosol concentration was maintained at all times. A 1-cm ID sampling probe was inserted horizontally 15 cm into the chamber and 30 cm from the bottom to sample the upstream concentration. A temperature and relative humidity probe were inserted into the chamber. Also, five other probes were inserted into the chamber in an identical fashion.

A set of five 47-mm BGI® filter holders housing 47-mm diameter disks of material being tested were connected to probes inserted into the upstream chamber in an identical fashion as the sampling probes. Ball valves were used to selectively control flow through each. The outlet side

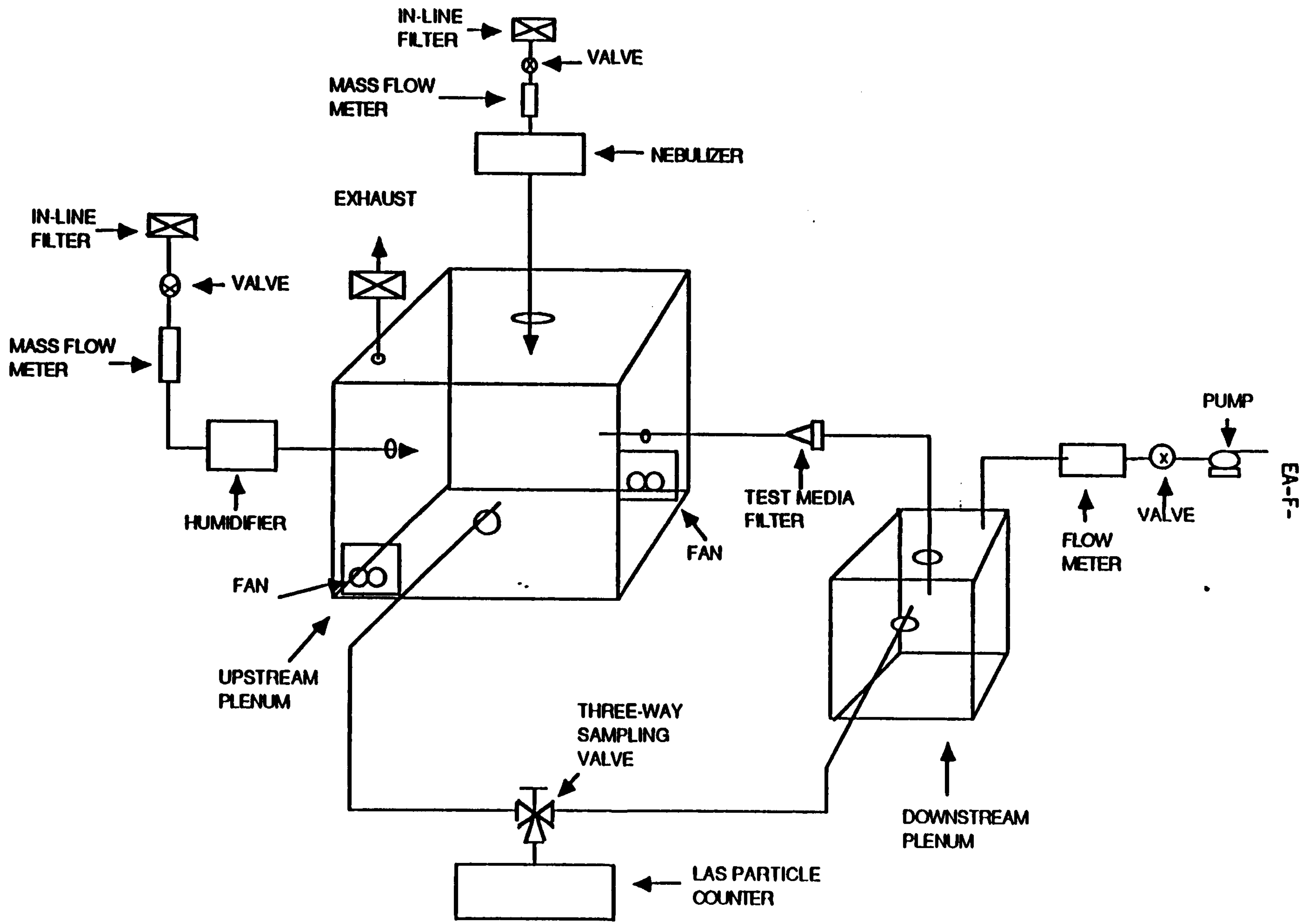


Figure A-2. PSL Aerosol Filter Efficiency Test Apparatus

the holders were grouped to a common 5-cm diameter PVC manifold. From this manifold a single line connected to the downstream chamber. The manifold is not shown and only one holder is shown for simplicity.

A vacuum pump was used to pull 18 lpm of air through the air tight, ~27 l (30cm x 30cm x 30cm) downstream chamber. The downstream chamber fills with air from the upstream chamber which was filtered by the test material. Similar to the upstream chamber, the downstream chamber had a fan for mixing and a sampling probe located 15 cm from the bottom and extended 10 cm into the chamber.

A Laser Aerosol Spectrometer (LAS, Particle Measuring Systems, Boulder CO) was used to measure the aerosol concentrations. The LAS counts the number of particles in size specific channels. This allowed for isolation of the penetration of ~1.1 μm particles, ignoring any submicron particles generated. A test was conducted by collecting three 30 second samples upstream. Sampling was then switched downstream. Approximately seven minutes were given for the downstream chamber to reach a representative steady state concentration before collecting three 30 second samples. Finally a second set of upstream samples were collected. The filtration efficiency (η%) is calculated from the upstream (U) and downstream (D) particle concentrations as follows:

$$\eta\% = \frac{U - D}{U} x\ 100\ \%$$

ARD

When testing with ARD, the system is much more straightforward. This test system is diagrammed in Figure A-3. A pneumatic powder dispersion system (Sibata, microdust feeder) was used to generate ~5 micron (AMMD) ARD aerosol at a mass concentration of 40 ± 10 mg/m^3. The temperature was maintained at 72 $\pm$ 4°F and the relative humidity at 85 $\pm$ 4%. The sampling probes and test material filter holders remain unchanged. The downstream side of the fines filter media holder was connected directly to another filter holder. This second filter holder houses an absolute filter (Millipore® type AA) used to collect the ARD penetrating the fines filter medium. An in-line flow meter and vacuum pump that pulls 18 lpm followed. Upstream filter samples were also collected on Millipore® AA filters. Tests were conducted by bracketing upstream measurements around every two or three downstream samples. Samples were collected at a flow rate of 18 lpm and

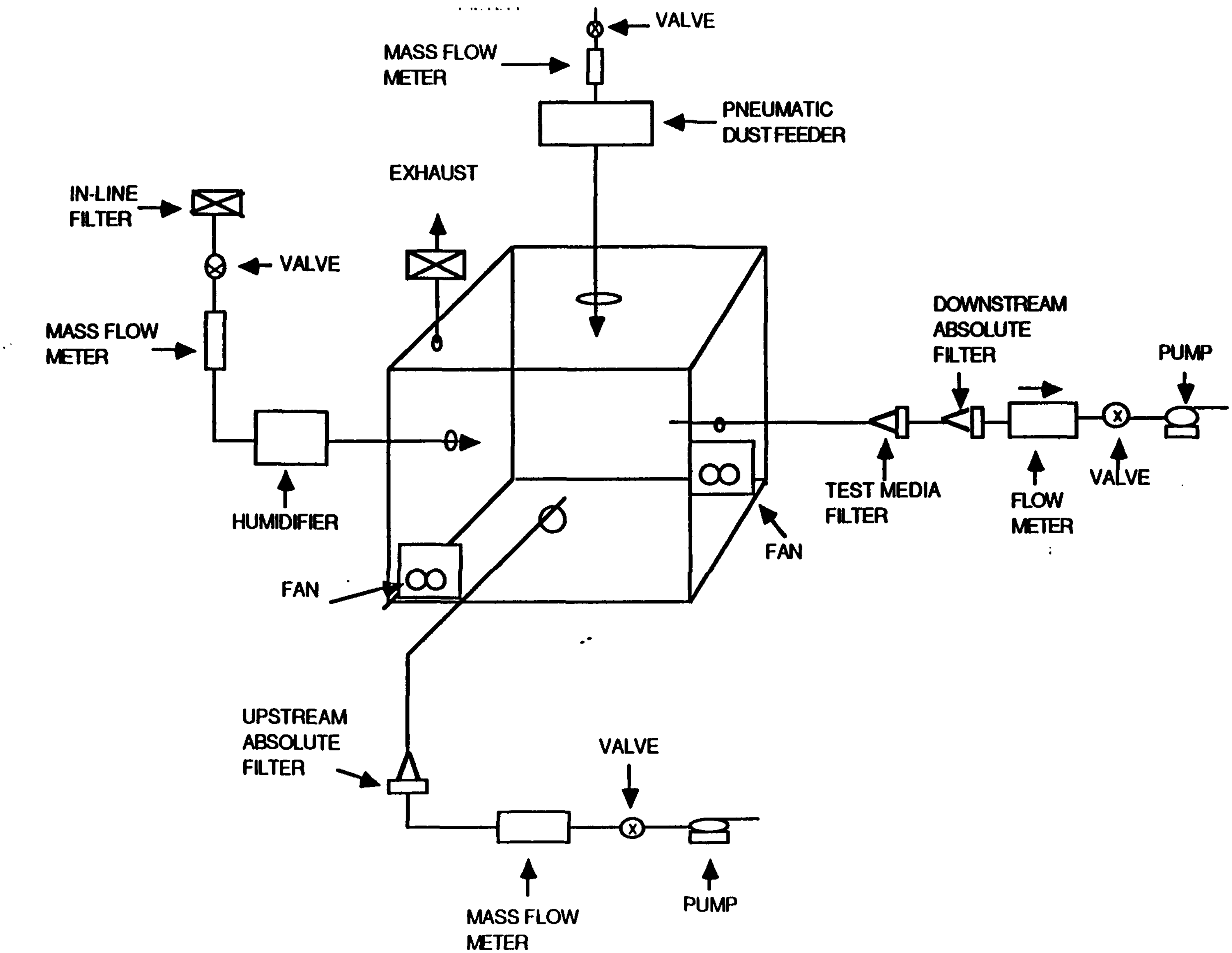


Figure A-3. ARD Aerosol Filter Efficiency Test Apparatus

around every two or three downstream samples. Samples were collected at a flow rate of 18 lpm and for 2 min durations. This provided ample mass for accurate gravimetric analysis. The mass collected on all the sample filters were determined gravimetrically in an environmentally controlled weighing room. The mass collected on upstream and downstream filters were used to calculate the test material filtering efficiency as given above.

The losses associated with both systems were evaluated to correct the measured particle concentrations. Samples were collected with no test material in the holder to determine the fraction of particles lost in the system during transport. This fraction was then used to determine the actual amount of particles removed by the filter medium.

<u>Silicon Carbide</u>

Aerosol filtration tests were also conducted with 31 and 50 μm particles. When such large particles are used, it is important to take measures to ensure credible data are obtained. The problems with these large particles are their high settling velocities and large inertia. Dispersed particles do not remain air-borne and, because of their inertia, can be difficult to collect as a representative sample. Mass concentrations were 100 ± 25 mg/m^3 for the 31 μm, and 40 ± 10 mg/m^3 for 50 μm particles.

Significant effort was required to establish a working test system and method. The test system employed was similar to that used for ARD efficiency tests. A schematic of the system is provided in Figure A-4. The primary difference is the orientation of injection and sampling ports. Particles are dispersed from the Sibata dust feeder and introduced to the chamber from the side (horizontally). The sampling probe is inserted vertically from the bottom. It has a gradual 90° curve so that the inlet of the probe samples horizontally. In preliminary tests to characterize the system, we found that the filters (especially the backup absolute filter) have to be horizontal, otherwise the particles were not retained on the medium. Attempts to sample from the top (inverted probe) and the side were not possible because particles bounced off the filter. Particle bounce was not eliminated when sampling from below, but when particles bounce, gravity helped to retain them on the medium. The 90° gradual curve on the sampling probe reduced the chance for sampling artifacts resulting from particles settling into the probe.

A special filter holder was fabricated to reduce particle losses between those penetrating the C2 fines medium and being collected on the absolute filter. A detailed schematic of

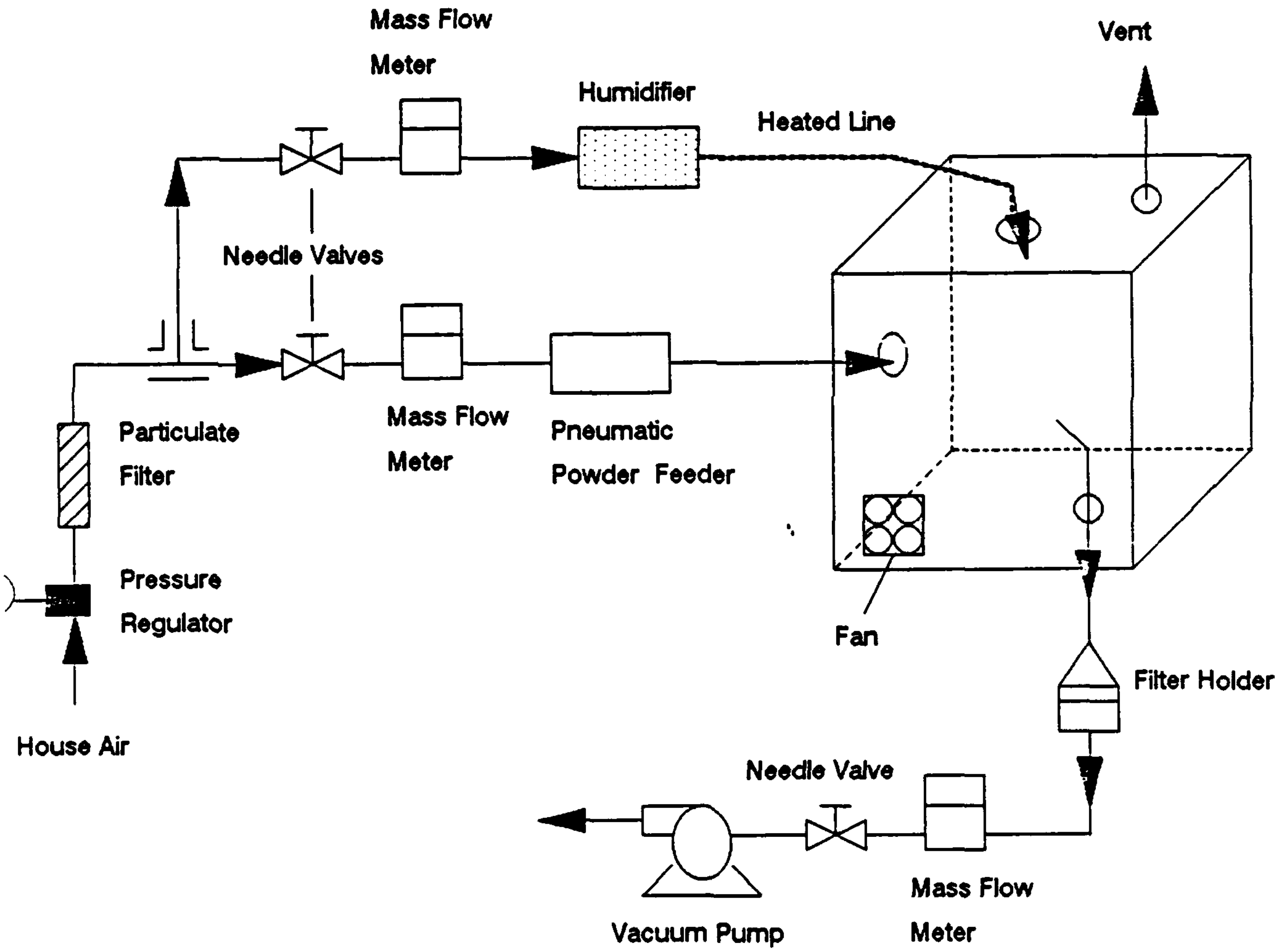


Figure A-4. Test Apparatus for Measuring Filter Efficiency with 20 and 50 μm Silicon Carbide Particles

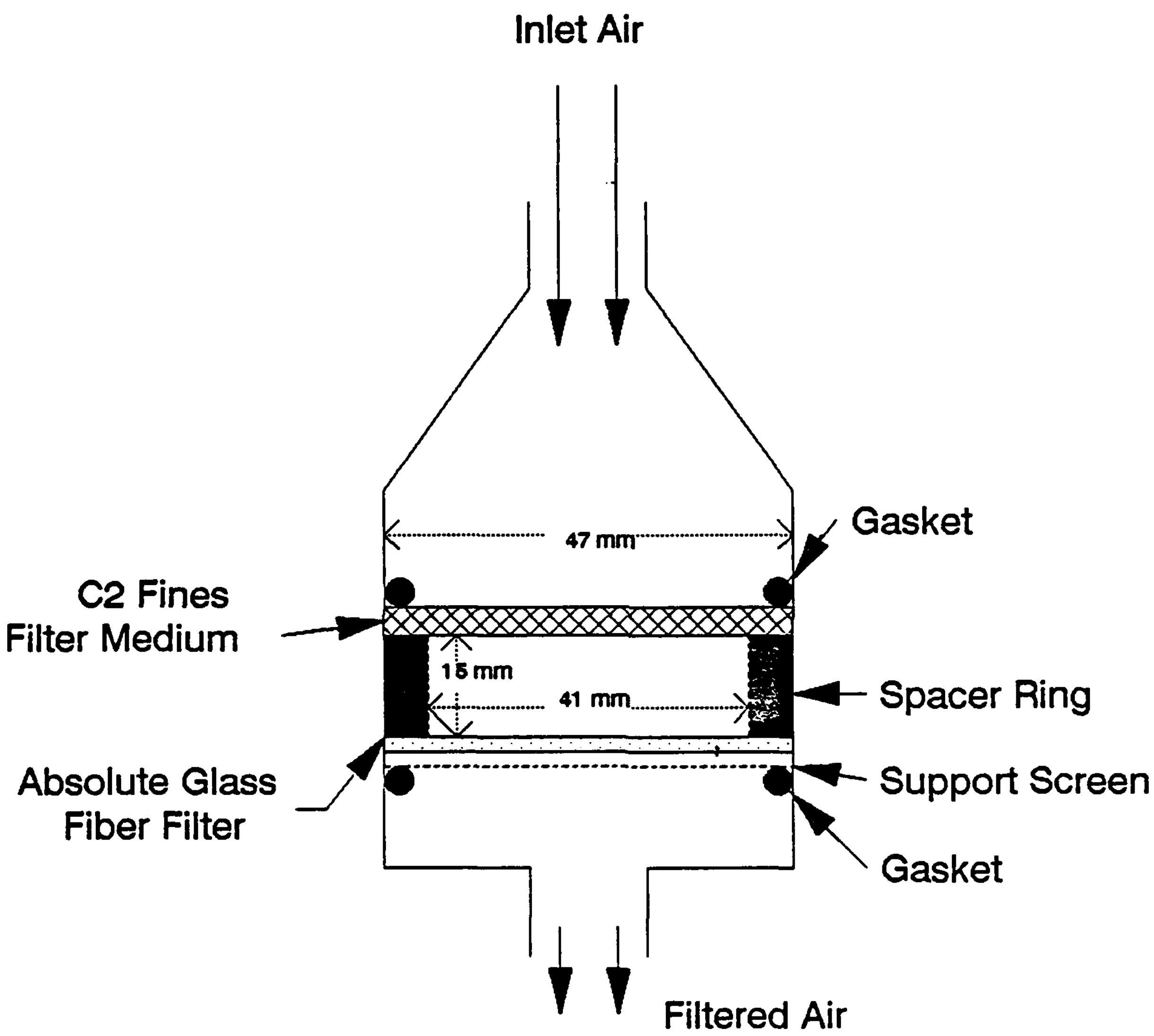


Figure A-5. Detailed Schematic of Filter Holder for Filtration Efficiency Test Apparatus

this holder is provided in Figure A-5. The C2 fines filter element was inserted so that the incoming particle-laden air passed through it first. The filter element was sealed and supported along the outer 3 mm rim. A 1.5 cm long cylindrical spacer ring separates the downstream absolute glass fiber filter which is supported by a screen. This arrangement provided the most direct method to collect the particles which penetrate the C2 fines medium without incurring losses during transport.

To determine filtration efficiency, tare weighed C2 fines and glass fiber filters were loaded into the filter holder. A flow rate of 13.8 lpm of challenge air was pulled through the 41 mm diameter open filter for three minutes. This provided adequate time to collect sufficient mass on the filters for gravimetric analysis. After sample collection, filter elements were removed and weighed to determine gross weight, and subsequently, net weight of particles collected. The mass of particles collected on each element was used to determine filtration efficiency ($\eta\%$) as follows:

$$\eta\% = \left(\frac{M_F}{M_F + M_A}\right) x\ 100\%$$

where M_F is the mass collected on the fines filter and M_A is the mass collected on the absolute filter. The challenge mass concentration (C, mg/m^3) can then be calculated from

$$C = \left(\frac{M_F + M_A}{Q * t}\right) * 1000$$

when Q is the sampling flow rate (lpm), t is the sample duration (min) and 1000 is a conversion from liters to cubic meters.

This procedure provides the most direct method to measure filtering efficiency. It is not sensitive to challenge concentration fluctuations and provides a challenge mass concentration for each sample. Corrections for transport losses to the C2 fines filter, sampling efficiency, and losses of particles that penetrate to the C2 fines filter, like that with the ARD method, are not necessary.

Charcoal Fines Emissions

Charcoal fines emissions were quantified using the Q261 shaker test and collecting fines on absolute filters. For a previous study for CRDEC*, standard operating procedures (SOPs) for operation of the Q261 shaker test and gravimetric analysis of filters were established. The text below gives an overview of the general procedure and then is followed by the specific shaking and weighing procedures.

Upon receipt, canisters were given Battelle identification numbers. These canisters were sorted by a randomized test sequence. Due to fabrication problems, canisters with type E filter media were tested at the end. Canisters with type A, B, C, and D media followed the randomized test sequence. Canisters were required to equilibrate in the test laboratory for a minimum of 24 hours prior to testing. The testing lab was maintained at a target temperature of 68 $\pm$ 4°F and a relative humidity of 40 $\pm$ 5 percent. During this canister equilibration period, the Millipore® filters to be used for sampling were also undergoing equilibration in a shelter within the test room.

Following the required equilibration period, the Q261 shaker testing was performed. The Q261 shaker testing procedure and the procedure for filter sample weighing are fully described in the following SOPs and summarized here. These activities were carried out in the laboratory in parallel. The filters were placed in labeled aluminum weighing dishes for storage and transport within the laboratory. This was done to minimize the tare weight of the samples being analyzed.

Three Q261 shakers were supplied for use in this project and run simultaneously on a test stand in our laboratory. The flow rate through each of the three Q261 shakers was verified each day prior to performing any testing, using the dry gas meter and canisters not designated for testing. Following this flow rate verification, each Q261 shaker was loaded with an appropriate canister according to the randomized order, and the tared filters were loaded into the filter holders. The master timer was set for 20 min and one switch started all three pumps and shaker motors. During the shaking of each set of three canisters, one of the shakers' flow rates was measured using a dry gas meter, and the flow rate was recorded to verify that the air flow rates were stable. At the completion of 20 min, the timer turned off power to all shakers and pumps and the elapsed time meter which was

*Kuhlman, M.R, Messman, J.D., and Osburn, A.J. "Chromium and Carbon Dust Emissions Tests for M10A1 and C2 Canisters," US Army CRDEC, Final Report, June 28, 1989.

used to measure test duration. A schematic depiction of the Q261 shaker testing apparatus is shown in Figure A-6.

At the termination of a shaker test, the filters were carefully returned to their weighing pans from the filter holders and their gross weights determined. This was accomplished as soon after the shaker test as practical in order to minimize the potential for effects from drift in room conditions or balance operation between tare and gross weighing of each filter. Following measurement of the filter gross weight, each filter was placed in a cleaned, labeled Petri slide for protection from contamination.

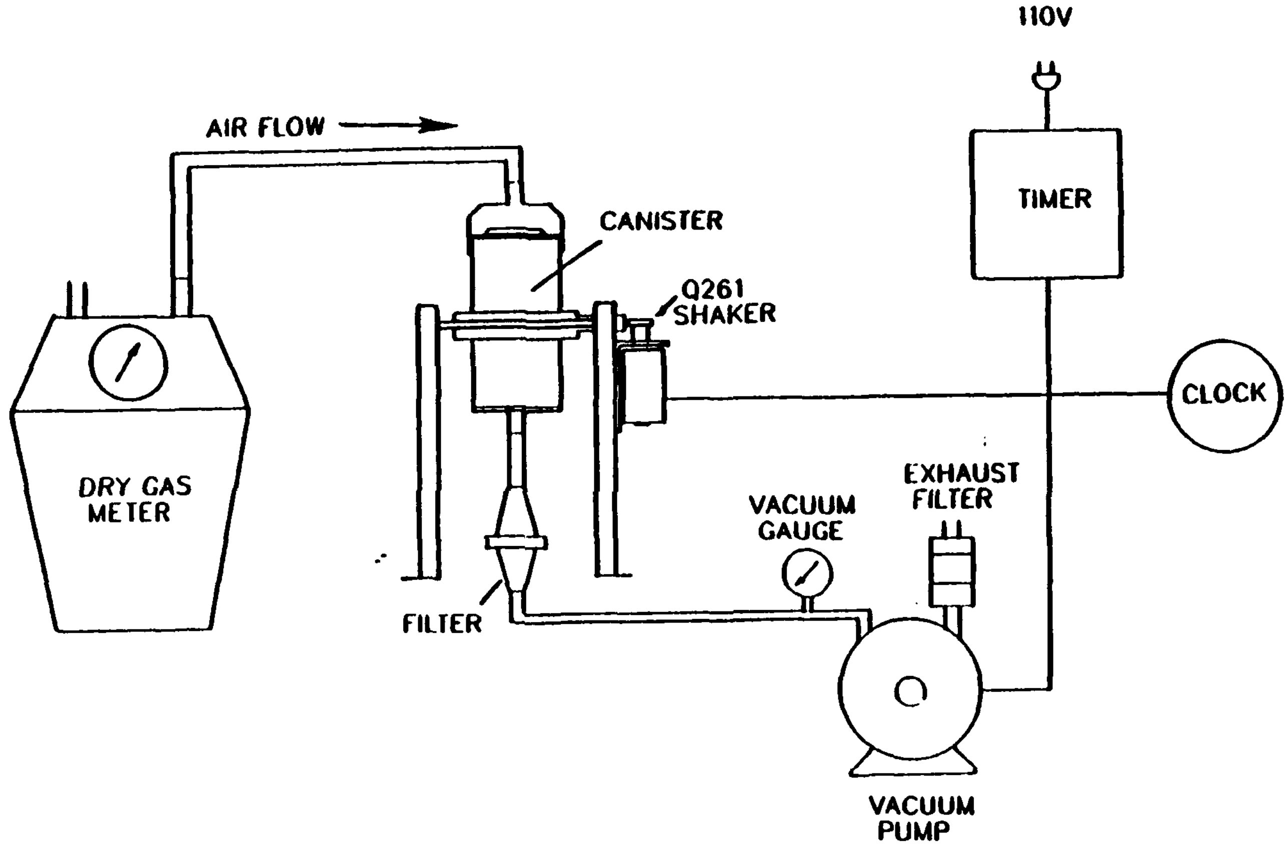


Figure A-6. Schematic of Q261 Shaker Testing Apparatus

STANDARD OPERATING PROCEDURE

for

PERFORMANCE OF Q261 SHAKER TESTS
WITH C2 CANISTERS

INTRODUCTION

Shaking of test canisters is performed to determine if charcoal is being released from the canisters under continuous use. The shaking consists of placing a test canister into the shaker and running the shaker for 20 minutes, while monitoring the test conditions. The filters that are used to collect the dust emitted from the canisters are gravimetrically analyzed to determine the mass.

SUMMARY

The purpose of this SOP is to make certain that the shaking process is performed accurately and consistently. The following procedures document the steps required in setting up and successfully running the Q261 shaker tests.

PROCEDURES

A. Instrumentation

A1. Balance Room

- Recording thermohumidigraph
- Sling psychrometer
- Humidifier/dehumidifier
- Heater/air conditioner

A2. Shaker

- Q261 shakers (3) with in-line switches firmly attached to a shaker platform
- Canisters: C2

B. Supplies

- 47-mm in-line BGI filter holders (3)
- Millipore 47-mm, 0.8 micron pore size, AA filters; these filters must be from the same lot number

- Filter holder adapters for C2 canister
- Vacuum pumps with vacuum gauges, must be capable of pulling at least 55 l/min through the test system
- 1/4" O.D. poly tubing
- 2 adjustable wrenches
- Timer (at least 30 minutes)
- Power strips
- Stopwatch
- Dry gas meter

C. Equilibration

- The plugs that seal the canisters will be removed and the canisters placed in the Balance Room, where the canisters will be allowed to equilibrate for 24 hours prior to testing.

D. Analytical Procedure

Select canister for test. Place the canister in the shaker with the inlet side of canister facing up.

Once the canister is in place a 47-mm filter holder is loaded with a spare filter, and attached to the bottom of the canisters with an adapter fastened to the outlet of the canister. For the C2 canisters the funnel-like adapter is screwed on the threads at the outlet of the canister. The spare canister used for the flow check is similarly adapted.

The outlet of the filter holder is connected to the vacuum side of the pump by poly tubing. The pumps are plugged into a wall outlet with their switches in the off position. Once everything for the flow check is set up, the pump is turned on and allowed a warmup time of at least 5 minutes.

The flow is checked by attaching the dry gas meter (DGM) to the inlet side of the canister/filter setup and timing three revolutions of the dial on the DGM (corresponding to 3 ft^3). The elapsed time is then recorded on the computer spreadsheet. The calculation to determine the flow rate is done automatically and printed in another column. The flow is considered acceptable if it falls in the range of 45 l/min ($\pm$ 5 l/min). If the flow falls outside this range, the connections are checked as well as the pump itself; the flow is then rechecked and i after these attempts the flow is still incorrect, the pump is replaced and flow rechecked.

Upon completion of the flow check, the filter holders are loaded with test filters. The pumps, shakers, and timer are plugged into the power strip. The power strip remains unplugged until actual test time. A final pretest check is made to ensure fittings are tight, switches are turned on, the time is turned to the last marker before zero, and canisters are labeled with preprinted labels. During the pretest check it is determined which of the shaker flows will be monitored with the DGM during the test.

When the test is ready to begin, the power strip is turned on. During the test the shaker setup, with the DGM attached, will be monitored and the data recorded in the record book;

this should be done at least twice each test. At the end of the test after the timer has interrupted power to the power strip, it is turned off. The canisters are removed from the shakers and the filters carefully unloaded and placed in their appropriate containers, which have the same number labels as the canister. The plugs are replaced on each canister.

E. Cleaning Procedure

The following procedures are performed on a routine basis to help prevent cross contamination.

E1. Between Tests

The filter holder top is disconnected from the canister adapter and the inside, as well as the O-ring are wiped clean with a Microwipe. If it is apparent that the wipe did not get rid of all of the loose debris, a "flux brush" is used to lightly, but thoroughly, dust the top and the O-ring.

E2. End of the Day

At the end of a test day, the filter holders (tops and bottoms) and canister adapters are taken completely apart and washed with warm water and Spray Nine using a soft bristle test tube brush. The parts are then thoroughly rinsed and allowed to air-dry overnight.

F. Operating Parameters

- Balance Room temperature = 68 ± 4 F; relative humidity = 40 ± 5%.

G. Calibration Procedure

- Calibration of the DGM is performed by Battelle's Instrument Lab using a reference spirometer on a 6-month basis or as deemed necessary.

Calculations

- Flow rate = 3 ft^3/revolution time
- Volume = flow rate x test duration.

STANDARD OPERATING PROCEDURE

for

GRAVIMETRIC ANALYSIS OF FILTER SAMPLES

INTRODUCTION

Gravimetric analysis of filter samples is required to determine the mass of particulate matter collected on filters. This analysis consists of weighing the filter media before and after sample collection under controlled conditions. The increase in mass of the filter is subsequently combined with the parameters describing the sample collection to yield a measurement of the airborne particulate mass concentration in the sample air.

SUMMARY

This SOP is intended to ensure that the filter samples are preconditioned and weighed under adequately controlled conditions and that the operation of the analytical balance is monitored during weighing operations to derive the maximum precision from the instrument. The following procedures describe the sample equilibration requirements, balance calibration, and quality assurance measures taken during filter weighing operations. These procedures are intended for application to 47-mm Millipore type AA filters and to exceed a requirement for 0.05 mg sensitivity.

PROCEDURES

A. Instrumentation

A1. Balance Room

- Recording thermohumidigraph
- Sling psychrometer
- Humidifier/dehumidifier
- Heater/air conditioner

A2. Balance

- Mettler Model UM3 microbalance
- Staticmaster antistatic bar or equivalent
- Class S weights set, calibrated against Class M
- Plastic tipped tweezers for weight handling
- Tweezers for filter and weighing disk handling

B. Reagents/Supplies

- Aluminum weighing pans
- Weighing paper
- Sufficient filters from one lot for all analyses

C. Standard Preparation

The standard preparation is the set of Class S weights. This set of weights should be calibrated annually against a set of Class M weights. For analysis of 47-mm Millipore AA filters, the standard weights of interest are the 5, 10, 50, 100, and 200 mg weights.

D. Analytical Procedure

D1. Filter Conditioning

Prior to tare weighing or gross weighing of filters, they must be stored, covered, for a minimum of 24 hr in the balance room under controlled conditions (68 $\pm$ 4 F, 40 $\pm$ 5% RH). Following tare weighing, the filters must be stored in labeled containers suitable for storage of the filters until they are transferred into filter holders for sample collection. The temperature and relative humidity of the balance room must be continuously recorded during filter equilibration periods, and the recording device must be calibrated at least weekly using a sling psychrometer or equivalent.

D2. Balance Preparation

Prior to performance of a series of weighings, the balance must undergo a five-point calibration with the Class S weights. This should be performed after the balance has been in the partial arrest position (to warm up) for at least 10 min. With no weight on the balance pan, the balance zero adjust is used to achieve an indication of zero.

D3. Filter Weighing

Following the balance calibration, the filters are weighed in groups of not more than five. Before and after each group the balance is zeroed. In any case where the balance zero deviates more than 10 μg from nominal, the preceding group of filters must be reweighed. If the deviation is less than 10 μg, no reweighing is needed, but the zero adjust should be used to bring the balance to nominal values.

For weighing of each filter, the filter should be transferred from its container to the balance pan using tweezers only. If the filter is likely to collect enough mass that material might be lost in handling, the filter should be tare weighed in an aluminum weighing dish. For each weighing, the filter should be placed on the pan while in the arrest position. With the balance door closed, each filter should be weighed a minimum of two times. After recording the first weight, the balance is returned to the arrest position, and the filter must be reweighed until two consecutive weights differ by less than 10 μg. As soon as possible after the filter weight is determined, the filter should be returned to its labeled container and replaced in a covered

area in the balance room. After the final gross weight has been determined, the filter can be transferred to a labeled container for subsequent analysis.

At some point during the weighing of a set of filters, the master filter should be weighed. The apparent weight of this filter during a project is intended to permit assessment of effects due to changes in the balance room environment or due to repeated handling of the filter.

E. Operating Parameters

- Balance room temperature = 68 ± 4 F; relative humidity = 40 ± 5%.

F. Calibration Procedures

Calibration of the balance is performed with a set of five or more weights from a set of Class S weights or better. The weights used should bracket the tare weight of the filters being analyzed. For 47-mm Millipore filters, the tare weight is 75-100 mg. After checking the zero of the balance, as described above, each of the five calibration weights is weighed twice with both values recorded. These values are entered into a log book or computer spreadsheet so that the balance performance can be tracked with time. If the indicated weights deviate in a consistent fashion by more than 1 percent from the actual values of the weights, factory recalibration of the balance is called for.

G. Calculations

The net weight is simply determined by subtracting the average of the tare weight values from the average of the gross weight values. This can be accomplished manually or by use of a validated software package.

Blank

APPENDIX B

TABULATION OF TEST RESULTS

Baseline Tests

- Mildew Resistance
- Tensile Strength
- Air Flow Resistance and Filtering Efficiency

C2 Canister Tests

- Air Flow Resistance, DOP Filtering Efficiency, and Fabricator's Production Comments

- Charcoal Fines Emissions

In the following results, the media are sometimes referred to by a letter identification. This was done so the subcontractors that performing the tests did not know the source of the materials. The letter ID relation to the media are:

- A (Foss Manufacturing OAG630)
- B (Ahlstrom Filtration R2817)
- C (Snow Filtration Style 342)
- D (Troy Mills Troytuf®)
- E (3M Company's Filtrete® G0104).

Results of Mildew Resistance Test

(From Bowser-Morner Report)

FACTUAL DATA

SECTION III - RESULTS OF TEST:

Tests were conducted as specified in Section II using the equipment as listed in Section I. The results obtained during testing of Five (5) Sets of Twenty (20) 2" x 2" Test Coupons for Fungus Resistance Testing are as following

At the completion of Seven (7) days incubation the Control Samples had visible evidence of slight fungus growth.

At the completion of Fourteen (14) days incubation the Control Samples had visible evidence of heavy fungus growth.

At the completion of the Twenty-One (21) days Fungus Test the Control Samples had visible evidence of very heavy fungus growth.

Test Coupons "A" had no visible evidence of Fungus Growth.

Test Coupons "B" had no visible evidence of Fungus Growth.

Test Coupons "C" had no visible evidence of Fungus Growth.

Test Coupons "D" had no visible evidence of Fungus Growth.

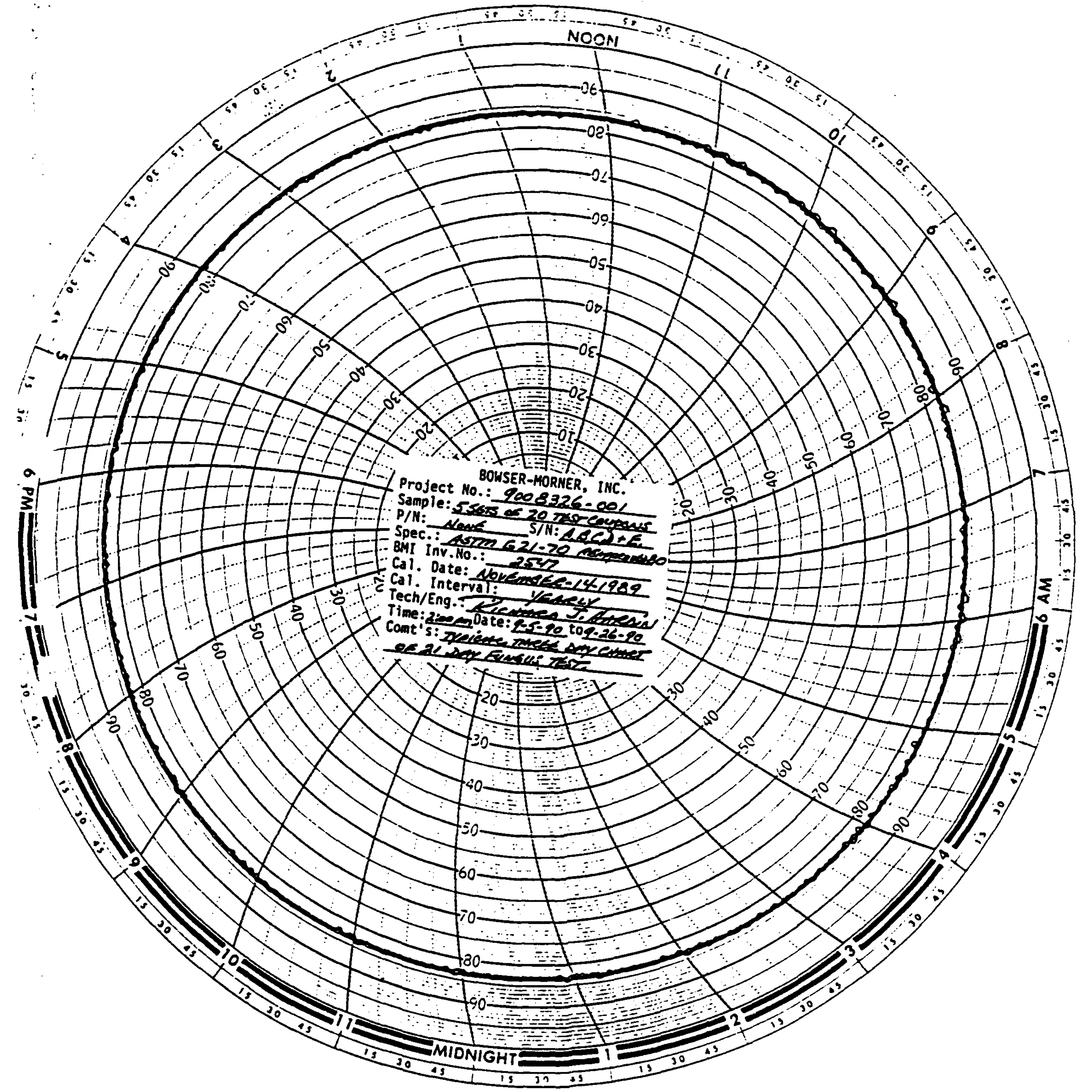
Test Coupons "E" had no visible evidence of Fungus Growth.

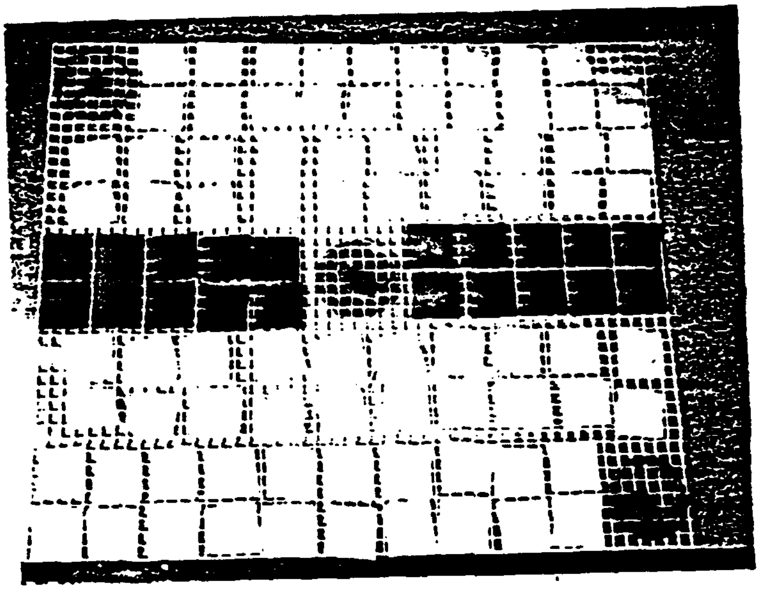
The Test Coupons were disposed of properly at the completion of the test per Client's Instruction.

FACTUAL DATA

SECTION IV - TEST DATA

TYPICAL 3 DAY FUNGUS TEMPERATURE/HUMIDITY CHART


NOON
MIDNIGHT
6 AM
6 PM
BOWSER-MORNER, INC.
Project No.: 9008326-001
Sample: 5 SETS OF 20 TEST COUPONS
P/N: NONE S/N: A,B,C,D+E.
Spec.: ASTM G21-70
BMI Inv.No.: 2547
Cal. Date: NOVEMBER-14-1989
Cal. Interval: YEARLY
Tech/Eng.: Richard J. Arlin
Time: 2:00 pm Date: 9-5-90 to 9-26-90
Comt's: TYPICAL THREE DAY CHART OF 21 DAY FUNGUS TEST



PHOTOGRAPH OF TEST COUPONS
AND CONTROL SAMPLES

FIGURE NO. 1

Results of Tensile Strength Test

(From Owens-Corning Fiberglas)

FILE: 48708 DATA1 A VM/SP CONVERSATIONAL MONITOR SYSTEM PAGE 00001

1 SUMMARY OF AVERAGE VALUES FOR BATTELLE FABRICS
BREAKING STRENGTH AND ELONGATION AT BREAK

REPORT 48708
ATTACHMENT 1

SAMPLE	DIRECTION	N	MEAN	STANDARD DEVIATION	C.V.	MINIMUM VALUE	MAXIMUM VALUE
BREAKING STRENGTH LBS :							
A	MD	10	58.830	5.991	10.183	49.600	67.500
A	CMD	10	29.570	4.048	13.688	24.800	35.300
B	MD	10	3.592	0.491	13.660	2.950	4.510
B	CMD	10	4.256	0.909	21.369	2.680	5.850
C	MD	10	20.850	1.993	9.558	17.600	22.900
C	CMD	10	19.210	0.930	4.843	18.000	20.600
D	MD	10	33.300	3.409	10.238	27.100	38.900
D	CMD	10	16.760	2.827	16.867	13.000	21.300
E	MD	10	24.240	3.455	14.254	19.500	29.700
E	CMD	10	7.558	1.620	21.437	5.210	9.660
ELONGATION AT PEAK LOAD % :							
A	MD	10	103.800	3.871	3.730	97.200	109.000
A	CMD	10	135.800	5.653	4.163	128.000	145.000
B	MD	9	45.356	5.799	12.786	37.700	57.900
B	CMD	9	60.411	17.399	28.801	29.500	82.300
C	MD	10	34.900	6.066	17.380	24.000	41.300
C	CMD	10	76.060	6.897	9.068	69.500	91.300
D	MD	10	149.200	5.574	3.736	141.000	159.000
D	CMD	10	259.900	16.003	6.157	235.000	288.000
E	MD	10	18.260	2.338	12.802	14.000	21.900
E	CMD	9	11.074	7.815	70.571	3.970	29.700

1 SUMMARY OF INDIVIDUAL VALUES FOR BATTELLE FABRICS REPORT 48708
BREAKING STRENGTH AND ELONGATION AT BREAK ATTACHMENT 2A

Sequence Testing	Specimen Number	Sample/ Direction	Material	Break-Strength lbs	Elongation %
1	62	D-CMD	D	15.1	262
2	46	C--MD	C	17.9	24.0
3	14	A-CMD	A	26.1	132
4	50	C--MD	C	19.6	41.3
5	92	E--MD	E	28.6	21.0
6	96	E-CMD	E	6.23	29.7
7	17	A--MD	A	62.8	104
8	47	C--MD	C	22.9	41.1
9	77	D--MD	D	33.3	145
10	65	D--MD	D	31.2	145
11	97	E-CMD	E	6.76	14.0
12	40	B-CMD	B	5.85	54.0
13	74	D-CMD	D	13.8	251
14	51	C-CMD	C	20.6	69.5
15	35	B--MD	B	3.38	37.7
16	37	B-CMD	B	2.68	29.5
17	25	B--MD	B	2.95	45.0
18	45	C--MD	C	17.6	26.9
19	91	E--MD	E	29.7	21.9
20	54	C-CMD	C	19.0	73.3
21	69	D-CMD	D	21.3	283
22	16	A--MD	A	67.2	103
23	44	C--MD	C	22.4	36.7
24	63	D-CMD	D	17.3	235
25	21	B-CMD	B	3.49	75.5
26	95	E-CMD	E	6.01	.
27	11	A-CMD	A	32.0	134
28	34	B-CMD	B	4.03	65.4
29	13	A-CMD	A	24.8	133
30	81	E--MD	E	23.2	16.3
31	73	D-CMD	D	16.9	248
32	86	E-CMD	E	9.61	5.98
33	79	D--MD	D	38.9	155
34	9	A--MD	A	53.4	109
35	78	D--MD	D	37.6	146
36	19	A--MD	A	49.6	107
37	85	E-CMD	E	7.89	13.8
38	28	B--MD	B	4.51	48.8
39	76	D-CMD	D	15.6	256
40	36	B--MD	B	4.03	.
41	64	D--MD	D	35.9	148
42	18	A--MD	A	55.5	108
43	32	B-CMD	B	4.94	50.8
44	5	A--MD	A	59.9	101
45	80	D--MD	D	32.0	150
46	12	A-CMD	A	25.0	130
47	93	E--MD	E	27.6	18.8
48	23	B--MD	B	3.87	57.9
49	10	A-CMD	A	35.3	143
50	72	D--MD	D	32.8	148

1 SUMMARY OF INDIVIDUAL VALUES FOR BATTELLE FABRICS REPORT 48708
BREAKING STRENGTH AND ELONGATION AT BREAK ATTACHMENT 2B

Sequence Testing	Specimen Number	Sample/ Direction	Material	Break-Strength lbs	Elongation %
51	24	B-CMD	B	3.70	82.3
52	61	D-CMD	D	19.0	267
53	41	C--MD	C	22.7	40.3
54	52	C-CMD	C	20.6	72.5
55	57	C-CMD	C	19.2	72.7
56	7	A--MD	A	67.5	105
57	3	A-CMD	A	27.3	128
58	15	A--MD	A	61.7	97.2
59	1	A-CMD	A	33.9	145
60	55	C-CMD	C	18.0	85.0
61	90	E--MD	E	19.5	14.0
62	20	A-CMD	A	26.2	140
63	75	D-CMD	D	20.7	257
64	83	E--MD	E	24.7	20.3
65	31	B-CMD	B	3.92	43.8
66	100	E--MD	E	20.5	17.7
67	71	D-CMD	D	13.0	252
68	89	E-CMD	E	8.64	9.53
69	67	D--MD	D	31.7	159
70	2	A-CMD	A	32.6	139
71	82	E--MD	E	24.3	17.7
72	27	B--MD	B	3.49	41.4
73	48	C--MD	C	22.7	39.5
74	94	E--MD	E	22.8	17.3
75	38	B--MD	B	3.22	46.3
76	53	C-CMD	C	18.7	76.7
77	56	C-CMD	C	18.5	91.3
78	8	A--MD	A	54.2	105
79	26	B--MD	B	3.44	42.0
80	42	C--MD	C	20.1	31.3
81	66	D--MD	D	27.1	155
82	70	D-CMD	D	14.9	288
83	30	B-CMD	B	5.15	64.4
84	43	C--MD	C	21.8	34.5
85	6	A--MD	A	56.5	98.8
86	39	B--MD	B	3.06	42.1
87	58	C-CMD	C	20.2	69.9
88	33	B-CMD	B	4.24	
89	84	E--MD	E	21.5	17.6
90	87	E-CMD	E	9.07	8.9
91	68	D--MD	D	32.5	141
92	88	E-CMD	E	9.66	8.80
93	60	C-CMD	C	18.8	75.0
94	29	B--MD	B	3.97	47.0
95	22	B-CMD	B	4.56	78.0
96	4	A-CMD	A	32.5	134
97	99	E-CMD	E	6.50	4.99
98	49	C--MD	C	20.8	33.4
99	59	C-CMD	C	18.5	74.7
100	98	E-CMD	E	5.21	3.97

Results of Air Flow Resistance and Filtering Efficiency Test

FOSS MANUFACURING OAG630

FILTERING EFFICIENCY (%)					AIR FLOW RESISTANCE (mmH2O)		
SAMPLE NO.	1.1 micron PSL	~5 micron ARD	31 micron SC	50 micron SC	SAMPLE NO.	COMPRESS	UNCOMPRESS
1	18	42	69	81	1	0.78	0.61
2	33	36	81	91	2	0.81	0.64
3	13	36	65	87	3	0.77	0.57
4	13	42	83	76	4	0.83	0.57
5	65	15	78	79	5	0.89	0.54
6	38	42	94	89	6	0.81	0.53
7	30	27	72	94	7	0.74	0.54
8	50	41	86	96	8	0.88	0.57
9	32	41	82	87	9	0.97	0.64
10	38	46	77	89	10	0.82	0.57
11	35	44	89	92	11	0.82	0.67
12	27		87	85	12	0.75	0.6
13	23	22	84	90	13	0.79	0.66
14	13	28	86	88	14	0.76	0.66
15	14	40	93	94	15	0.83	0.53
16	37	46	81	94	16	0.79	0.61
17	34	47	80	73	17	0.8	0.59
18	20	44	73	83	18	0.94	0.73
19	20	49	84	66	19	1.04	0.59
20	21	42	79	95	20	0.8	0.69
AVG	29	38	81	87		0.83	0.61
STD	13	9	8	8		0.08	0.06
MIN	13	15	65	66		0.74	0.53
MAX	65	49	94	96		1.04	0.73

ALHSTROM FILTRATION R2817

FILTERING EFFICIENCY (%)					AIR FLOW RESISTANCE (mmH2O)		
SAMPLE NO.	1.1 micron PSL	~5 micron ARD	31 micron SC	50 micron SC	SAMPLE NO.	COMPRESS	UNCOMPRESS
1	8	40	28	10	1	0.5	0.64
2	27	50	43	18	2	0.5	0.51
3	17	34	55	39	3	0.5	0.64
4	67	36	35	41	4	0.36	0.38
5	62	43	29	34	5	0.42	0.52
6	28	25	31	26	6	0.54	0.41
7	29	41	44	25	7	0.46	0.4
8	56	22	19	40	8	0.45	0.27
9	25	44	24	13	9	0.46	0.44
10	37	32	15	47	10	0.49	0.44
11	39	52	37	63	11	0.5	0.33
12	38	49	13	49	12	0.52	0.53
13	32	46	22	44	13	0.46	0.52
14	13	42	38	13	14	0.53	0.41
15	23	16	24	51	15	0.49	0.41
16	35	41	37	33	16	0.52	0.41
17	31	29	20	48	17	0.43	0.46
18	32	49	26	51	18	0.52	0.53
19	52	27	16	43	19	0.52	0.52
20	53	53	34	38	20	0.42	0.5
AVG	35	39	29	36		0.48	0.46
STD	16	11	11	15		0.05	0.09
MIN	8	16	13	10		0.36	0.27
MAX	67	53	55	63		0.54	0.64

SNOW FILTRATION STYLE 342

FILTERING EFFICIENCY (%)					AIR FLOW RESISTANCE (mmH2O)		
SAMPLE NO.	1.1 micron PSL	~5 micron ARD	31 micron SC	50 micron SC	SAMPLE NO.	COMPRESS	UNCOMPRESS
1	14	38	87	90	1	0.68	0.7
2	17	24	90	93	2	0.72	0.66
3		27	89	94	3	0.68	0.58
4	67	25	90	94	4	0.84	0.72
5	24	44	91	95	5	0.89	0.72
6	34	38	91	97	6	0.71	0.53
7	30	42	90	88	7	0.75	0.61
8	42	46	87	98	8	0.68	0.64
9	32	26	93	98	9	0.73	0.74
10	13	39	93	97	10	0.76	0.68
11	18	37	86	94	11	0.77	0.68
12	38	23	85	96	12	0.73	0.7
13	35	35	86	96	13	0.83	0.62
14	33	19	92	97	14	0.74	0.67
15	18	67	82	97	15	0.76	0.68
16	15	58	84	95	16	0.82	0.62
17	10	25	86	97	17	0.78	0.55
18	28	44	91	97	18	0.68	0.72
19	1	42	83	97	19	0.7	0.56
20	6	42	83	94	20	0.89	0.68
AVG	25	37	88	95		0.76	0.65
STD	15	12	4	3		0.07	0.06
MIN	1	19	82	88		0.68	0.53
MAX	67	67	93	98		0.89	0.74

TROY MILLS TROYTUF

FILTERING EFFICIENCY (%)					AIR FLOW RESISTANCE (mmH2O)		
SAMPLE NO.	1.1 micron PSL	~5 micron ARD	31 micron SC	50 micron SC	SAMPLE NO.	COMPRESS	UNCOMPRESS
1	14	32	40	38	1	0.52	0.48
2	26	31	36	47	2	0.78	0.46
3	34	42	43	41	3	0.7	0.38
4	32	39	57	49	4	0.78	0.46
5	36	35	49	38	5	0.67	0.33
6	31	30	34	44	6	0.69	0.34
7	18	36	33	51	7	0.68	0.47
8	19	33	35	58	8	0.61	0.52
9	40	53	36	51	9	0.68	0.51
10	27	27	24	52	10	0.72	0.43
11	8	10	31	54	11	0.68	0.43
12	1	15	40	51	12	0.64	0.43
13	5	50	38	60	13	0.69	0.45
14	27	64	38	47	14	0.78	0.45
15	24	43	34	56	15	0.78	0.45
16	34	47	38	54	16	0.79	0.48
17	31	43	30	27	17	0.85	0.46
18	38	48	42	29	18	0.73	0.49
19	35	48	38	46	19	0.77	0.45
20	56	49	37	34	20	0.82	0.48
AVG	27	39	38	46		0.72	0.45
STD	13	13	7	9		0.08	0.05
MIN	1	10	24	27		0.52	0.33
MAX	56	64	57	60		0.85	0.52

3M COMPANY FILTRETE G0104

SAMPLE NO.	FILTERING EFFICIENCY (%) 1.1 micron PSL	~5 micron ARD	31 micron SC	50 micron SC	AIR FLOW RESISTANCE (mmH2O) SAMPLE NO.	COMPRESS	UNCOMPRESS
1	55	71	69	71	1	0.75	0.66
2	54	80	80	85	2	0.76	0.79
3	57	63	77	90	3	0.7	0.63
4	46	62	76	85	4	0.72	0.62
5	37		86	89	5	0.85	0.62
6	82	66	79	89	6	0.85	0.62
7	56	63	90	90	7	0.64	0.6
8	51	63	85	93	8	0.63	0.65
9	46	73	63	96	9	0.82	0.72
10	46	70	88	92	10	0.75	0.68
11	50	57	55	96	11	0.71	0.95
12	66	62	81	93	12	0.98	0.8
13	69	60	78	89	13	0.78	0.71
14	55	73	84	95	14	0.64	0.75
15	47	51	76	91	15	0.97	0.8
16	49	59	71	97	16	0.83	0.72
17	42	51	85	96	17	0.82	0.6
18	35	62	77	99	18	0.9	0.76
19	60	81	70	93	19	0.9	0.83
20	56	80	89	72	20	0.93	0.88
AVG	53	66	78	90		0.80	0.72
STD	11	9	9	7		0.11	0.10
MIN	35	51	55	71		0.63	0.6
MAX	82	81	90	99		0.98	0.95

Results of C2 Canister Air Flow Resistance Test, DOP Aerosol Filtering Efficiency Test, and Fabricator's Production Comments

(From Racal Filter Technologies, Ltd.)

FOSS MANUFACTURING'S OAG630

SAMPLE NO.	PERCENT	PENATRATION	AIR FLOW RESISTANCE mm H2O	
	32 lpm	85 lpm	32 lpm	85 lpm
1	0.0036	0.0046	13.5	39
2	0.0003	0.0015	13.8	40
3	0.001	0.004	13.4	39
4	0.0004	0.0014	13.6	40
5	0.0005	0.0018	13.5	39
6	0.0004	0.0015	13.3	39
7	0.0003	0.0018	13.5	40
8	0.0009	0.004	13.6	39
9	0.0004	0.0033	14	41
10	0.0012	0.0035	13	38
11	0.0009	0.0025	13.4	39
12	0.0004	0.0023	13.6	40
13	0.0005	0.0025	12.6	37
14	0.0006	0.0016	13.1	39
15	0.001	0.0033	13.1	38
16	0.0007	0.0021	13.2	39
17	0.0006	0.0031	12.8	38
18	0.0008	0.0032	13	38
19	0.0007	0.0028	13.4	39
20	0.001	0.0029	13.2	38
21	0.0016	0.0033	13.4	39
22	0.0004	0.003	13.3	39
23	0.0008	0.0026	12.6	37
24	0.0008	0.0018	13.5	39
25	0.0004	0.0019	13.1	39
26	0.002	0.0032	13.7	40
27	0.0005	0.0021	13.2	38
28	0.0006	0.0016	13.7	40
29	0.0006	0.0027	13.6	40
30	0.0009	0.0035	13.2	40
31	0.001	0.003	12.8	37
32	0.0006	0.0033	13.8	40
33	0.0008	0.0021	13.1	38
34	0.0011	0.0021	13.5	39
35	0.0007	0.0028	13	38
36	0.0013	0.0038	13.1	38
37	0.0011	0.0038	13.2	38
38	0.0007	0.0025	12.9	37
39	0.0004	0.0016	13.5	39
40	0.0005	0.002	13.3	39
41	0.0033	0.0068	12.4	36
42	0.0022	0.0047	13	38
43	0.0007	0.0032	12.[illegible]	37
44	0.0007	0.0036	13.8	40
45	0.0004	0.0025	13.3	39
46	0.0003	0.0018	13.2	39
47	0.0017	0.0024	13.1	38
48	0.0004	0.0026	13.2	38
49	0.0006	0.0033	12.9	37
50	0.0007	0.0035	13.9	41
AVG	0.0009	0.0028	13.3	38.7
MAX	0.0036	0.0068	14.0	41.0
MIN	0.0003	0.0014	12.4	36.0
STD	0.0007	0.0010	0.3	1.1

AHLSTROM FILTRATION'S R2817

SAMPLE NO.	PERCENT PENETRATION		AIR FLOW RESISTANCE mm H2O	
	32 LPM	85 LPM	32 lpm	85 lpm
1	0.0031	0.0055	12.9	35
2	0.0011	0.0026	12.6	35
3	0.0008	0.0014	13	35
4	0.0013	0.0034	12.9	35
5	0.0012	0.003	12.4	34
6	0.0008	0.0036	12.8	35
7	0.0009	0.0029	12.5	34
8	0.0025	0.0042	13.2	36
9	0.0011	0.0029	12.7	35
10	0.0015	0.0024	12.5	34
11	0.0017	0.0035	12.7	35
12	0.0014	0.0036	12.4	34
13	0.0013	0.0027	12.9	35
14	0.0014	0.0038	12.7	35
15	0.0012	0.0031	12.9	35
16	0.0007	0.0026	12	33
17	*.0285	*.0296	13.5	38
18	0.0021	0.0047	12.9	35
19	0.0013	0.0024	13.1	36
20	0.0018	0.0031	12.7	35
21	0.0012	0.0035	12.3	34
22	0.001	0.0036	12.5	34
23	0.001	0.0032	12.5	34
24	0.0009	0.0021	12.6	35
25	0.0015	0.0042	12.8	35
26	0.0009	0.0019	13.3	36
27	0.0015	0.0032	13	36
28	0.0019	0.0038	13.5	37
29	0.0004	0.0031	12.5	34
30	0.0015	0.0024	12.8	35
31	0.0011	0.002	13.1	36
32	0.0027	0.0043	12.8	35
33	0.001	0.002	12.9	36
34	0.0011	0.0016	12.6	34
35	0.0021	0.0033	12.8	35
36	0.0077	0.0081	13.3	36
37	0.0012	0.0029	11.6	32
38	0.0066	0.0102	12.8	35
39	0.0019	0.0032	12.4	34
40	0.001	0.0021	12.6	34
41	0.0017	0.0029	12.5	34
42	0.001	0.0024	12.4	34
43	0.001	0.0012	13.2	36
44	0.0013	0.0014	13	36
45	0.001	0.0033	13.4	37
46	0.0015	0.0034	12	33
47	0.0007	0.0018	13.3	36
48	0.0011	0.0032	12.6	35
49	0.0016	0.0034	12.9	35
50	0.0011	0.0032	12.5	34
AVG	0.0015	0.0032	12.8	34.9
MAX	0.0077	0.0102	13.5	38.0
MIN	0.0000	0.0000	11.6	32.0
STD	0.0013	0.0016	0.4	1.1

SNOW FILTRATION'S STYLE 342

SAMPLE NO.	PERCENT PENETRATION		AIR FLOW RESISTANCE mmH2O	
	32 lpm	85 lpm	32 lpm	85 lpm
1	0.0007	0.002	12.5	36
2	0.0008	0.0024	13.2	38
3	0.0006	0.002	13.2	39
4	0.0005	0.0029	12.8	37
5	0.0009	0.0026	13.1	38
6	0.0016	0.004	12.7	37
7	0.0007	0.003	13	38
8	0.0081	0.0099	12.7	37
9	0.0004	0.0024	12.9	38
10	0.0015	0.0037	12.5	37
11	0.001	0.0028	13.1	38
12	0.0009	0.0031	12.7	37
13	0.001	0.0028	12.9	37
14	0.0005	0.0029	13.3	39
15	0.0008	0.003	12.9	37
16	0.0005	0.0029	12.7	37
17	0.0007	0.003	13	38
18	0.0005	0.0024	12.7	37
19	0.0006	0.0033	12.7	37
20	0.0003	0.002	12.8	37
21	0.0006	0.002	12.6	36
22	0.0007	0.0029	12.5	36
23	0.0008	0.0032	13.3	39
24	0.0003	0.0017	13	38
25	0.0006	0.0028	12.6	37
26	0.0015	0.003	13	38
27	0.0006	0.0025	12.9	37
28	0.0019	0.004	12.4	36
29	0.0004	0.0028	12.2	35
30	0.0002	0.0015	12.7	37
31	0.0014	0.0039	12.9	38
32	0.0002	0.0015	13.1	38
33	0.0003	0.0012	13	38
34	0.0004	0.0024	12.6	37
35	0.0006	0.0024	13	38
36	0.0005	0.0022	12.8	37
37	0.0007	0.0028	12.1	35
38	0.0003	0.0012	13.3	38
39	0.0005	0.0028	12.7	37
40	0.0002	0.0013	13.4	33
41	0.0005	0.0024	12.3	36
42	0.0006	0.0024	13	38
43	0.0002	0.0019	12.6	37
44	0.0008	0.0025	12.7	37
45	0.0002	0.0016	12.9	37
46	0.0005	0.0027	13	38
47	0.0005	0.0031	13	38
48	0.0004	0.0025	12.5	37
49	0.0011	0.0022	12.6	37
50	0.0004	0.0016	12.9	38
AVG	0.0008	0.0027	12.8	37.3
MAX	0.0081	0.0099	13.4	39.0
MIN	0.0002	0.0012	12.1	35.0
STD	0.0011	0.0012	0.3	0.9

TROY MILLS' TROYTUF

SAMPLE NO.	PERCENT PENETRATION		AIR FLOW RESISTANCE mmH2O	
	32 lpm	85 lpm	32 lpm	85 lpm
1	0.0007	0.0017	13.5	37
2	0.0028	0.004	13.9	39
3	0.0011	0.0016	13.4	37
4	0.001	0.0037	13.7	38
5	0.0018	0.0021	13.9	39
6	0.0008	0.0012	13.5	38
7	0.0016	0.0024	13	36
8	0.002	0.002	13.5	38
9	0.0011	0.0021	13.1	36
10	0.0022	0.004	14	39
11	0.0021	0.0027	13.4	37
12	0.002	0.0017	13.3	37
13	0.0017	0.0022	14.1	39
14	0.0021	0.0022	14	39
15	0.0012	0.0023	13.3	37
16	0.0018	0.0035	14.4	40
17	0.0016	0.0015	13.8	38
18	0.0015	0.003	14	39
19	0.0015	0.0036	14.4	40
20	0.0019	0.0048	14	39
21	0.0012	0.0031	14.4	40
22	0.0015	0.0015	14	39
23	0.002	0.0015	13.9	38
24	0.0014	0.0032	13.2	38
25	0.0024	0.0055	13.4	37
26	0.0016	0.0043	13.3	37
27	0.0012	0.0036	13.5	38
28	0.0022	0.0024	13.1	36
29	0.001	0.0035	13	36
30	0.0036	0.005	13.3	37
31	0.0014	0.0021	13.4	37
32	0.0006	0.0015	13.3	36
33	0.0015	0.0015	14.2	39
34	0.0017	0.0015	13.7	38
35	0.001	0.002	14.3	40
36	0.0019	0.0038	13.7	38
37	0.0011	0.0028	13.5	38
38	0.0008	0.0018	13.2	36
39	0.0017	0.0026	13.7	38
40	0.0009	0.0024	14	39
41	0.0013	0.002	13.7	38
42	0.0017	0.0024	14	39
43	0.0022	0.0026	13.8	38
44	0.0017	0.0019	13.9	39
45	0.0013	0.0012	13.9	39
46	0.002	0.0026	13	36
47	0.0014	0.002	13.5	37
48	0.0014	0.0027	13	36
49	0.0016	0.0021	13	36
50	0.0022	0.0033	14.2	39
AVG	0.0016	0.0026	13.6	37.9
MAX	0.0036	0.0055	14.4	40.0
MIN	0.0006	0.0012	13.0	36.0
STD	0.0006	0.0010	0.4	1.2

3M COMPANY'S FILTRETE G0104

SAMPLE NO.	PERCENT PENETRATION		AIR FLOW RESISTANCE mmH2O	
	32 lpm	85 lpm	32 lpm	85 lpm
1	0.0018	0.0085	14.6	46
2	0.0013	0.0051	14.5	46
3	0.0014	0.0069	14.9	47
4	0.0011	0.0063	13.9	44
5	0.0015	0.0065	14.9	43
6	0.0018	0.0088	15.1	48
7	0.0016	0.0087	14.7	47
8	0.0011	0.0053	15.5	49
9	0.0017	0.0076	14.3	45
10	0.0017	0.0077	14.2	45
11	0.0015	0.0081	13.7	43
12	0.001	0.0048	13.4	42
13	0.0015	0.0089	13.6	43
14	0.001	0.0058	14	44
15	0.0013	0.0088	14.7	46
16	0.0015	0.0073	14	44
17	0.0011	0.0099	13.3	42
18	0.0006	0.0049	14.7	47
19	0.0016	0.0088	14	44
20	0.0009	0.0066	13.9	44
21	0.0016	0.0082	14.5	46
22	0.0013	0.0088	14.8	47
23	0.0019	0.0086	14.3	45
24	0.0017	0.0081	14.1	44
25	0.0005	0.0051	14.4	46
26	0.0016	0.0074	15.5	48
27	0.0014	0.0078	14	43
28	0.0012	0.0053	15.5	48
29	0.0012	0.0047	14.7	45
30	0.0016	0.0066	13.8	42
31	0.0019	0.0063	15.7	49
32	0.0015	0.0065	15.5	48
33	0.0011	0.0051	14	42
34	0.0017	0.0031	15.6	48
35	0.0016	0.0061	15.3	40.8
36	0.0015	0.0049	15.5	48
37	0.0016	0.0068	15	46
38	0.0012	0.0048	15.4	47
39	0.0009	0.0036	15.5	48
40	0.0018	0.0057	14.5	40.4
41	0.0012	0.0038	15	46
42	0.0017	0.0056	15.7	48
43	0.0018	0.0061	15.6	48
44	0.0012	0.0036	15.8	49
45	0.0016	0.0044	15	45
46	0.0017	0.0064	14.5	44
47	0.002	0.0063	15.8	48.2
48	0.0011	0.0043	16.5	51
49	0.0011	0.0046	15	46
50	0.0006	0.0032	14.4	44
AVG	0.0014	0.0063	14.7	45.6
MAX	0.0020	0.0099	16.5	51.0
MIN	0.0005	0.0031	13.3	40.4
STD	0.0004	0.0017	0.7	2.4

Reference: <u>Battelle C2 Filters, Battelle P.O. W-9951</u>

Test canisters manufactured using various fines filter media, standard C-2 construction otherwise. Comments and observations as follows:-

Material A:
- Welded very well.
- Very easy to handle.
- Seals very well in body.
- From assembly perspective a very good material.

Material B:
- Welds fairly well.
- Very difficult to handle, as this material is very "hairy". Hairs catch on fingers, clothing, table, other fines filters, etc.
- Material seems to be highly charged with static electricity - tended not to want to stay down in the welding jig.
- Tended to stick on welding head.
- Operator could not keep up to staking machine with this material.
- Does not conform very well to edge of canisters; material is too stiff to easily form a curled edge.

Material C:
- Welds very well.
- Material is very slippery and difficult to pick up; made welding operation somewhat difficult for operators. Had difficulty removing material from jig after welding. Operator had to stop staking machine several times to catch up.
- Material is very stiff and does not conform very well to inside of canister. Tends to buckle and leave large gaps which could result in carbon leaks. Careful handling and fitting was therefore required when installing.

Material D:
- Welds well.
- Fairly easy to handle but not as easy as material A.
- Fits well around body.
- From assembly perspective a good material.

Material E:
- Was unable to weld material E. This material seems to have a very low melting temperature, resulting in welding machine melting through both fines material and Vexar.
- Sticks to welder head.
- Material is fairly easy to handle.

Reference: <u>Battelle C2 Filters, Battelle P.O. W-9951</u> - (continued)

- Due to mesh the material is very stiff and will not conform to the body.
- We could not manufacture samples using this material.
- Could possibly use if disc size reduced to allow slight clearance fit in canister, and if vexar backing eliminated.

Results of C2 Canister Charcoal Fines Emission Test

CHARCOAL FINES EMISSIONS (mg)

SAMPLE NO.	FOSS MFG OAG630	AHLSTROM FILTRATION R2817	SNOW FILTRARION STYLE 342	TROT MILLS TROYTUF	3M COMPANY FILTRETE G0104
1	0.680	1.025	0.775	1.210	0.884
2	0.385	0.625	0.240	1.810	0.572
3	1.486	0.760	0.184	0.573	0.618
4	1.012	1.032	0.016	0.099	0.658
5	0.087	0.027	1.026	1.753	0.576
6	0.045	0.025	0.880	0.521	0.744
7	0.086	1.013	0.127	0.691	0.923
8	0.002	0.450	1.253	0.799	1.752
9	0.835	0.621	0.090	0.122	0.830
10	0.626	0.660	0.082	0.161	1.077
11	0.500	0.651	0.095	0.754	2.660
12	0.486	0.672	0.048	0.546	1.966
13	0.671	0.676	0.055	0.740	1.043
14	0.450	0.681	0.629	0.607	1.070
15	0.738	0.779	0.711	0.462	1.132
16	0.729	0.696	0.677	0.812	1.136
17	0.244	0.669	0.576	0.828	0.806
18	0.819	0.187	0.547	0.862	0.779
19	0.763	0.883	0.672	0.502	3.495
20	0.526	0.460	0.654	0.530	0.762
21	0.459	0.499	0.827	0.443	0.775
22	0.408	0.556	0.673	0.598	0.815
23	0.457	0.520	0.759	0 528	0.557
24	0.387	0.566	0.674	0.617	0.579
25	0.431	0.525	0.662	0.395	2.838
26	0.693	0.807	0.740	0.493	0.720
27	0.588	0.459	0.831	0.351	0.850
28	0.595	0.612	0.806	0.447	2.143
29	0.583	0.545	0.736	0.545	2.252
30	0.593	0.613	0.422	0.563	0.753
31	0.571	0.524	0.465	0.771	0.659
32	0.085	0.535	0.570	0.557	0.633
33	0.324	0.517	0.588	0.483	0.386
34	0.436	0.479	0.541	0.439	0.384
35	0.532	0.526	0.587	0.492	0.207
36	0.529	0.821	0.608	0.638	0.302
37	0.587	0.361	0.562	0.565	0.611
38	0.510	0.574	0.188	0.643	0.323
39	0.589	0.594	0.361	0.568	0.471
40	0.632	0.390	0.414	0.459	0.514
41	0.547	1.004	0.471	0.566	0.638
42	0.533	0.368	0.645	0.231	0.616
43	0.659	0.611	0.574	0.242	1.043
44	0.377	0.617	0.329	0.297	0.638
45	0.389	0.541	0.273	0.349	0.729
46	0.614	0.509	0.435	0.570	0.731
47	0.649	0.140	0.415	0.315	1.412
48	0.336	0.414	0.491	0.558	0.582
49	0.559	0.112	0.477	0.118	0.678
50	0.580	0.436	0.333	0.534	1.626
AVG	0.528	0.567	0.516	0.575	0.979
STD	0.248	0.228	0.269	0.324	0.684
MIN	0.002	0.025	0.016	0.099	0.207
MAX	1.486	1.032	1.253	1.810	3.495